Eastern Bering Sea Walleye Pollock Stock Assessment with Yield Considerations for 1999

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Executive Summary

The current draft SAFE chapter was compiled under new guidelines developed by the NMFS/AFSC to improve the readability of the chapters in addition to enhancing consistency between species. The primary focus of this chapter is on the eastern Bering Sea region. The Aleutian Islands Region and Bogoslof Island area are treated separately in Sections 1.15 and 1.16 on pages 60 and 62, respectively.

This chapter updates the draft presented to the Council in September for discussions with the Plan Team and SSC. We made the following changes from the statistical age-structured model (SAM) presented in 1997. We developed model code for computing the values related to MSY (F_{msy} B_{msy}, etc.) beyond simple yield-per-recruit analyses. This uses the estimates for either the Beverton-Holt or Ricker forms of the stock-recruitment relationship and takes into account estimates of fishery selectivity. We implement this using essentially the same information as for the final 1997 SAFE but with one year added to the model and assuming a total removal of 1.1 million tons in 1998. The 1998 NMFS bottom-trawl survey estimate of population numbers at age is used. The total estimated biomass from the bottom-trawl survey for 1998 is 2.21 million tons, down 27% from the 1997 survey estimate (3.03 million tons). The most abundant age group in the survey was represented by the 1992 year class. The most recent survey estimate from the echo integration trawl survey (EIT) on the EBS shelf was conducted in 1997 and was introduced in last year's assessment.

NMFS observer sampling of pollock catch for age and size composition was evaluated and new data for the 1997 fishery were included for analyses. Also, estimates of the average weights-at-age from the fishery data are presented. Analyses of growth by cohort from 1996 – 1997 (e.g., average weight increase of 4 year-old pollock in 1996 compared to 5 year-olds in 1997) suggest lower than average growth occurred. This may reflect changes in the distribution of the fishery or possibly conditions of available prey and consumption.

Preliminary results on re-evaluating the level of F_{msy} and B_{msy} indicate that estimates are sensitive to assumptions about selectivity and other model assumptions. This severely inhibits the use of previous estimates for EBS pollock F_{msy} since its computation assumed knife-edged selectivity at age 3. To avoid complications which arise over interpretation of selectivity assumptions, we provide estimates of F_{msy} in terms of the level of spawning exploitation rate (SER; Thompson 1996, Mace *et al.* 1996; computed here as the annual fraction of removal of spawning stock for a given fishing mortality rate). This was determined to be about 32% at MSY levels. Recent SER values have been around 20%. We conclude that based on new information, the continuing use of previous estimates for F_{msy} may be inappropriate. In fact, recently published technical guidelines (Restrepo *et al.* 1998) indicate that if the selectivity assumed for computing MSY values is substantially different from that in the fishery, then the MSY values may be inappropriate for determining stock status. The methods and results presented below attempt to provide reasonable alternatives to past MSY computations.

Computations leading to 1999 ABC alternatives based on the $F_{40\%}$ and F_{msy} are **1.01** and **1.45** million tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value). The 1999 overfishing level (OFL) alternatives for the reference model are **1.55** and **1.897** corresponding to $F_{30\%}$ and F_{msy} (arithmetic mean). Issues extraneous to these harvest levels include current uncertainty about changes in harvest rates on the EBS stock outside of the US EEZ (particularly for pre-recruit age groups), continuing decline in Steller sea lion populations in adjacent areas, and the recent observations that the biological and physical environment is changing. We believe that some of the uncertainty of the current and future environmental conditions has been factored into this assessment and that appropriate precautionary measures have been implemented. For example, 1999 harvests of 1 million tons have only about 15% chance of being greater than the corresponding 1999 F_{msy} harvest level. Harvest of 1 million t in 1999 is also considerably lower than the risk-averse strategy advised under Tier 1 in Amendment 44 where the harmonic mean of F_{msy} is recommended.

Harvest levels for the Aleutian Islands and Bogoslof regions are computed in the same way as last year. The **ABC values are 23,760 t and 17,000 t** for the Aleutian Islands region and Bogoslof area, respectively. The corresponding **overfishing levels are 31,680 t and 23,000 t.**

1.1. Introduction

The stock structure of Bering Sea pollock (*Theragra chalcogramma*) is not well defined. In the U.S. portion of the Bering Sea pollock are considered to form three stocks for management purposes. These are: eastern Bering Sea which consists of pollock occurring on the eastern Bering Sea shelf from Unimak Pass to the U.S.-Russia Convention line; Aleutian Islands Region which encompasses the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and Central Bering Sea -Bogoslof Island pollock, which are thought be a mixture of pollock that migrate from the U.S. and Russian shelves to the Aleutian Basin around the time of maturity. In the Russian EEZ, pollock are considered to form two stocks, a western Bering Sea stock centered in the Gulf of Olyutorski, and a northern stock located along the Navarin shelf from 171°E to the U.S.- Russia Convention line. The northern stock is believed to be a mixture of eastern and western Bering Sea pollock with the former predominant. Currently, scientists at the AFSC are collaborating on a genetics study that will help clarify issues surrounding stock structure.

1.2. Catch history and fishery data

From 1954 to 1963, pollock were harvested at low levels in the Eastern Bering Sea and directed fisheries began in 1964. Catches increased rapidly during the late 1960s and reached a peak in 1970-75 when catches ranged from 1.3 to 1.9 million t annually (Fig. 1.1). Following a peak catch of 1.9 million t in 1972, catches were reduced through bilateral agreements with Japan and the USSR.

Since the advent of the U.S. EEZ in 1977 the annual average eastern Bering Sea pollock catch has been 1.2 million t and has ranged from 0.9 million in 1987 to nearly 1.6 million t in 1991 while stock biomass has ranged from a low of 4-5 million to highs of 12-14 million t. Since implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977, catch quotas have ranged from 0.95 to 1.3 million t (Fig. 1.1). In 1980 United States vessels began harvesting pollock and by 1987 they were able to take 99% of the quota. Since 1988 the harvest has been taken exclusively by U.S. vessels.

Foreign vessels begin fishing in the mid-1980's in the international zone of the Bering Sea (commonly referred to as the "Donut Hole"). The Donut Hole is entirely contained in the deep water of the Aleutian Basin and is distinct from the customary areas of pollock fisheries, namely the continental shelves and slopes. Japanese scientists began reporting the presence of large quantities of pollock in the Aleutian Basin in the mid-to-late 1970's, but large scale fisheries did not occur until the mid-1980's. In 1984, the Donut Hole catch was only 181 thousand t (Fig. 1.1, Table 1.1). The catch grew rapidly and by 1987 the high seas catch exceeded the pollock catch within the U.S. Bering Sea EEZ. The extra-EEZ catch peaked in 1989 at 1.45 million t and has declined sharply since then. By 1991 the donut hole catch was 80% less than the peak catch, and data for 1992 and 1993 indicate very low catches (Table 1.1). A fishing moratorium was enacted in 1993 and only trace amounts of pollock have been harvested from the Aleutian Basin by resource assessment fisheries.

Fishery characteristics

The general pattern of the fishery since 1995 has been to have an "A-season" opening on January 20th with the season lasting about 1 month, depending on the catch rate. A second "B-season" opening occurs on September 1st (though 1995 opened on Aug 15th). The catch rates by tow and within these seasons shows that catch rates in the A-season are significantly higher than in the "B-season" and that the "A-season" catch rates in 1998 were the highest on record while the "B-season" dropped slightly (Fig. 1.2; 1998 data are preliminary). Please note several factors unrelated to abundance or biological changes can affect catch-per-tow—we include it here only as a descriptive information.

A-Season: Since the closure of the Bogoslof management district (518) to directed pollock fishing in 1992, the A-season pollock fishery on the eastern Bering Sea (EBS) shelf has been concentrated primarily north and west of Unimak Island (see Figs. 1.3-1.5 in Wespestad et al. 1996). Depending on ice conditions and fish distribution, there has also been effort along the 100 m contour between Unimak Island and the Pribilof Islands. This pattern has continued for the A-seasons of 1997 and 1998 (Figs. 1.3 and 1.4). The total catch estimates by sex for the A-season compared to the fishery as a whole indicates that over time, the number of males and female has been fairly equal (Fig. 1.5). The 1997 A-season had a slightly higher incidence of females but overall, males slightly outnumbered females. The length frequency information from the fishery shows that the size of pollock is generally larger than 40 cm but with some smaller fish caught during years when a strong year-class appeared (Fig. 1.6).

B-Season: After 1992, the B-season fishery has been conducted to a much greater extent west of 170°W than it had been prior to 1992 (see also Figs. 1.3-1.5 in Wespestad et al. 1996). This is a reflection of the implementation of the CVOA in 1992, the distribution of pollock by size on the eastern Bering Sea shelf, and the desire of the fleet to catch pollock larger than 35 cm. The length frequency information from this fishery reveals the marked progression of the large 1989 year-class growing over time and the incursion of the 1992 year-class in 1996 and 1997 (Fig. 1.7).

Trends in mean pollock size: Overall the average length of pollock in the catch was about 47 cm from 1991-1997. By area, pollock in the Aleutian Islands consistently average more than 50 cm, while pollock in the southeast BS are of intermediate average size (Fig. 1.8). The average length of pollock in the northwest portion of the EBS (west of 170W) is smaller than either the Aleutian or southeast portion of the BS. Over time, the SE portion had a smaller mean length in 1993 and has increased since then while the average length of fish in the NW region has declined somewhat (Fig. 1.8).

This year we examined the annual variability in the average growth of pollock in response to concerns over smaller than average fish. Since the fishery data are very extensive with large numbers of pollock measured for length, weight, and age, we used this to evaluate average growth in weight increases over time. Estimates of the average weights-at-age from the fishery suggest that annual variability in individual growth in weight is highly variable (Fig. 1.9). Based on analyses of growth by cohort from 1996 – 1997 (e.g., average weight increase of 4 year-old pollock in 1996 compared to 5 year-olds in 1997) suggests that lower than average growth occurred. This may reflect changes in the distribution of the fishery, differences in optimum temperature regimes for pollock growth, or possibly shifts in prey availability and consumption.

The pattern of weight increase with age provides a curious result. The average annual growth (in kg) decreases from ages 4 – 6, and then appears increase again with older ages. Preliminary examinations of bottom-trawl survey estimates of average weights-at-age suggest a similar pattern is also present from those samples. This may indicate that the pattern is not due to the target age-classes of the fishery.

1.2.1. Fisheries catch Data

Significant quantities of pollock are discarded and must be taken into account in estimation of population size and forecasts of yield. Observer length frequency observations indicated that discarded pollock include both large and small pollock. Since observers usually sample the catch prior to discarding, the size distribution of pollock sampled closely reflects that of the actual *total* catch. Discard data as compiled by the NMFS Alaska Regional Office have been included in estimates of total catch since 1990.

Pollock catch in the eastern Bering Sea and Aleutian Islands by area from observer estimates of retained and discarded catch, 1990-1997 are shown in Table 1.2. Discarded pollock since 1990 has ranged from a high of 11% of total pollock catch in 1991 to a low of 6.3% in 1996. Pollock discards in 1994 were 7.7%, slightly lower than in 1993, and decreased further in 1995 to 7.4%, and 6.3% in 1996. In 1997 the discard estimate increased to 8.2%. The magnitude of these discards is accounted for within the population assessment since these total harvest estimates are available by seasonal and spatial strata.

We estimate catch age composition using the methods described by Kimura (1989) and modified by Dorn (1992). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: 1) INPFC area 51 from January - June (the "A" season); 2) INPFC area 51 from July - December (the "B" season); and 3) INPFC area 52 from January - December. This method was used to derive the age compositions from 1991-1996 (the period for which all the necessary information is readily available). Prior to 1991, we used the same catch - age composition estimates as presented in Wespestad *et al.* (1996). The time series of the proportion estimated at each age is presented in Fig. 1.10. Data values used in the age-structured model for catch-at-age for 1964-1996 are given in Table 1.3. while the sampling effort for the lengths and processed otoliths are shown in Table 1.4.

1.3. Resource surveys

1.3.1. Bottom trawl surveys

Trawl surveys have been conducted annually by the AFSC to assess the abundance of crab and groundfish in the Eastern Bering Sea. Until 1975 the survey only covered a portion of the pollock range. In 1975 and since 1979, the survey was expanded to encompass most of the range of pollock. Since 1984 the biomass estimates have been relatively high and showed an increasing trend through 1990 (Table 1.5). Between 1991 and 1996 the bottom trawl survey biomass estimate has ranged from 3.2 to 5.5 million t. A general decline in stock size has become apparent in the past few years relative to the first half of the 1990's (Fig. 1.11).

The general distribution of walleye pollock in 1998 was similar to previous years with major concentrations around the Pribilof Islands, and in the northwest corner of the survey area (Fig. 1.12). Specific anomalies in pollock distribution include somewhat higher catch rates around St. Lawrence Is. than usual, and an extension farther into Bristol Bay than we see in cold years (but typical of warm years). The abundance estimate for the bottom trawl survey was 2,210,000 t with the 95% confidence interval of about +/- 20% based on sampling variability alone. This is the lowest biomass estimate for the bottom trawl portion in the standard survey area since 1981.

Preliminary 1998 abundance estimates by length revealed dominant length modes at 15, 22, and 41 cm (Fig. 1.13a). Although age 2 pollock are rarely caught in abundance on the shelf in bottom trawl surveys, subsequent preliminary age abundance estimates (Fig. 13b) support previous observations that the abundance of the 1996-year class may be above average. Abundance estimates of age 1 pollock (the 1997 year-class), suggest below average levels but the variability about these estimates is quite large based on past performance. The number of hauls and pollock sampled for lengths and ages are presented in Table 1.6.

1.3.2. Echo-integration trawl (EIT) surveys

Whereas bottom trawl surveys are conducted annually and assess pollock from the bottom to 3 m off bottom, EIT surveys have been conducted triennially since 1979 to estimate pollock in midwater (Traynor and Nelson 1985). An EIT survey was also conducted in 1996 (outside the triennial series) to address concerns about recruitment.

The most recent EIT pollock survey was carried out 16 July - 6 September, 1997 westward from Port Moller, Alaska to the U.S./Russia Convention Line. The details of this survey were presented in Wespestad *et al.* (1997). Biomass of pollock in midwater (from near the surface to 3 m from the bottom) was estimated at 2.59 million tons with 0.8 million tons east of 170^{o} W longitude and 1.8 million tons west of 170^{o} W longitude. The time series of estimated EIT survey proportions at age is presented in Fig. 1.14. The number of trawl-hauls, and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.7.

1.4. Analytic approach

1.4.1. Model structure

The SAM analysis was first introduced in the 1996 SAFE (Ianelli 1996) and was compared with the cohort-analysis method that has been used extensively for pollock in past years. Since the cohort-analyses methods can be thought of as special cases of the SAM analysis (e.g., as shown in Ianelli 1997), we have not continued the use of VPA/cohort algorithms due to their limitations in dealing with many aspects of data in a statistical sense. The statistical age-structured approach has also been documented from analyses performed on simulated data for the Academy of Sciences National Research Council (Ianelli and Fournier 1998). Other changes from last year's analyses include:

- The 1998 EBS bottom trawl survey estimate of population numbers-at-age was included.
- We estimate F_{msy} and related quantities within the model.
- We compute the Spawning Exploitation Rate (SER) as a uniform way of treating the effect of fishing on the spawning stock. This value is simply the percentage reduction in spawning output that is incurred by fishing activities (e.g., a value of 10% implies that the spawning biomass will be reduced by that amount due to fishing in the current year).
- We begin the model in1964 for the purpose of evaluating the stock-recruitment relationship (results presented in 1997 were based on analyses beginning in 1978).

The technical aspects of this model are presented in Appendix 1 and expand somewhat from the details presented in Ianelli (1996) and Ianelli and Fournier (1998). Briefly, the model structure is developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). We implemented the model using automatic differentiation software developed as a set of libraries under C++. These libraries, coupled with the model-building scripting software, enables a set of tools useful for non-linear parameter estimation for large problems. An added benefit is the potential for performing high dimensional integration required to use Bayesian methods and to evaluate more fully the effect of multivariate parameter uncertainty on management quantities of interest.

1.4.2. Parameters estimated independently

Natural Mortality and maturity at age

Currently, we have assumed fixed natural mortality-at-age values based on studies of Wespestad and Terry (1984). These provide estimates of M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively. These values have been used since 1982 in catch-age models and forecasts and appear to approximate the true rate of natural mortality for pollock. Recent studies on Gulf of Alaska pollock indicate that natural mortality may be considerably higher when predators are taken explicitly into account. This may also hold for the EBS region, however, the abundance of pollock is proportionately much higher than all other fish species compared to the Gulf of Alaska. This may explain why cannibalism is much more common in the EBS than in the Gulf. Note that to some degree, the role of cannibalism is modeled through the implementation of a Ricker (1975) stock-recruitment curve. This curve can take the form where having higher stock sizes may result in lower average recruitment levels.

Maturity at age was assumed to be the same as that given in Wespestad (1995). These values are given here together with the baseline assumption of natural mortality-at-age:

Age	1	2	3	4	5	6	7	
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	
Prop. Mature	0.000	0.008	0.290	0.642	0.842	0.902	0.948	
Age	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
M	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop. Mature	0.964	0.970	1.000	1.000	1.000	1.000	1.000	1.000

The current model has been configured to evaluate uncertainty in natural mortality rate and this is presented below under *Model Evaluation*.

Length and Weight at Age

Length, weight, and age data have been collected extensively for pollock. Samples of length-age and weight-length data within each stratum indicate growth differences by sex, area, and year-class. General patterns have been that pollock in the northwest area are slightly smaller at age than in the southeast. Since our estimates of harvests-at-age are stratified by area (and season), these differences are taken into account prior to analyses within the model. For the fishery we use year (when available) and age-specific estimates of average weights at age as computed from the fishery age and length sampling programs. These values are shown in Table 1.8 and are important for converting model estimated catch-at-age (in numbers) to estimated total annual harvests (by weight). Since we do not assume a fishery catch-effort relationship explicitly, the fishing mortality rates depend largely on the total annual harvests by weight. For the bottom-trawl and EIT surveys, we tune the model to estimates of total numbers of fish.

1.4.3. Parameters estimated conditionally

For the reference model presented here, 637 parameters were estimated. These include vectors describing recruitment variability in the first year (as ages 2-15 in 1964) and the recruitment deviations (at age 1) from 1964-1998. Additionally, projected recruitment variability was also estimated (using the variance of past recruitments) for five years (1999-2003). The two-parameter stock-recruitment curve is included in addition to a term that allows the average recruitment prior to 1964 (that comprises the initial age composition in that year) to have a mean value different than subsequent years. Thus there are 57 parameters that comprise initial age composition and subsequent recruitment values.

Fishing mortality is parameterized to be semi-separable. That is, there is a year component and an age (selectivity) component. The age component is allowed to vary over time with changes allowed every three years. The age component is constrained such that it's mean value will be equal to one, this means that it will not be confounded with the time component (see Section 1.14, Model details). Also, we assume that the age-component parameters are constant for the last 4 age groups (ages 12-15). Therefore, the time component of fishing mortality numbers 35 parameters (estimable since we place low variance on the likelihood component on the total catch biomass) and the added age-time component of variability results in a matrix 12x11 matrix of 132 parameters. This brings the total fishing mortality parameters to 168. Please note however, that in standard cohort analyses such as that of Pope (1972) the number of parameters for a similarly dimensioned problem would be 35x15 or 525 fishing mortality parameters. Of course in a VPA, these parameters are not estimated statistically, rather implicitly using an algorithm that assumes no errors in the total catch-at-age.

For the bottom trawl survey a similar parameterization for the selectivity-at-age estimates includes an overall catchability coefficient, age and year specific deviations in the average availability-at-age which totals 188 parameters for these data. Similarly, for the EIT survey, which began in 1979, these parameters number 221. Estimates for changes in EIT selectivity sometimes occur for years when the survey was not conducted. This increases the number of parameters we estimate, but avoids problems associated with surveys occurring on irregularly spaced intervals. The idea of estimating these changes is to allow some continuity in unaccounted-for variability of fish available to our survey gear. That is, we expect things to change in this regard but our null hypothesis is that the survey operation is constant with respect to relative changes in age class availability.

Finally, 3 additional fishing mortality rates are estimated conditionally. These are the values corresponding to the $F_{40\%}$, $F_{35\%}$ and $F_{30\%}$ harvest rates. These rates satisfy the constraint that given selectivity-at-age vector (we used the mean selectivity from 1989 to 1998), proportion-mature-at-age, natural mortality rate, and weight at age, there are unique values that correspond to the fishing mortality rates.

The likelihood components can thus be partitioned into the following groups:

- Total catch biomass (Log normal, σ=0.05)
- Bottom trawl and EIT survey abundance indices, (Log normal, σ=0.2)
- Fishery and survey proportions-at-age estimates (Robust quasi-multinomial (effective sample size of 200 for fishery, 30 for surveys). These values were selected based on comparisons of catch-at-age variance estimates obtained from the fishery stratified sampling scheme (Kimura 1989) with values obtained in earlier fits to the stock assessment model (Ianelli 1996, Table A1, Annex B).
- Selectivity constraints (penalties on age-age variability, time changes, and non-decreasing (with age) patterns
- Recruitment variability (Log normal, σ=0.9)

1.5. Model evaluation

As part of the continuing process of examining model assumptions and data sensitivities, we present results from an array of different model configurations. Some of these are in response to specific requests by the NPFMC family and others are intended to illustrate some properties of model behavior relative to the extensive surveys and fishery observations conducted by the AFSC for walleye pollock. A list of some of the models include:

Model 1 **Reference model–**637 parameters; future selectivity based on most recent 10-year average (medium-term selectivity estimate).

Model 2 same as reference model but with future selectivity based on most recent (3-year) estimate (short-term selectivity estimate).

Model 3 same as reference model but with selectivity for future years based on average selectivity since 1964 (long-term selectivity estimate).

Model 4 same as reference model but survey selectivities constant over time.

Model 5 same as reference model but survey AND fishery selectivities constant over time.

Model 6 same as reference model but added term to estimate natural mortality for ages 3 years and older.

Model 7 same as reference model but with the effect of the 1978 year-class removed from influencing the stock-recruitment relationship.

Model 8 same as reference model but with the OSCURS effect on recruitment added.

Model 9 expected recruitment constant with respect to stock size (though annual recruitment is still stochastic).

Models 2 and 3 were carried out to determine the effect of alternative assumptions about future selectivity estimates and affect only quantities related to F_{msy} determinations and future projections.

Models 4 and 5 examine different assumptions about the amount that survey and fishery selectivity levels are allowed to change over time.

Model 6 evaluates the impact of estimating the natural mortality rate for older age pollock (ages 3 and older) relative to the reference assumption.

In Model 7 we examine the influence of removing the large 1978 year-class on estimating the stock-recruitment relationship. Since the stock-recruitment curve affects estimates of F_{msy} and B_{msy}, we considered inferences about the fitted curve to be important.

In Model 8, we added the effect of the environment as presented in last-year's assessment using output from the surface-driven model of Bering Sea currents (OSCURS, Wespestad *et al.* 1997).

Finally, in Model 9 we assumed that recruitment has no relationship with spawning stock size and that for all levels of biomass, the expected recruitment was the same. This renders MSY-type computations valid only in the sense of yield per recruit analyses.

Relative to the reference case (Model 1) the alternatives can be more broadly categorized as:

a) Primarily affecting assumptions about fishery/survey observations and the ability to fit observations consistently (Models 4 and 5);

b) Affecting assumptions about pollock stock dynamics (i.e., natural mortality rate—Model 6, stock-recruitment relationship constant—Models 7, 8, and 9); and

c) Primarily affecting future selectivity assumptions (Models 2 and 3);

An evaluation of the goodness of fit for the models is presented in Table 1.9. Predictably, results from Models 4 and 5 fit the data extremely poorly compared to the other models. Model 5, with the fewest number of parameters, had the worst fit to the observed data. The variance about current stock size was higher for Model 1 compared to Models 4 and 5 based on the coefficients of variation (CV's as presented in parentheses in Table 1.10). This reflects the fact that with more parameters involved, fewer assumptions are required at a cost of higher variance. It can be argued that most modern stock assessment models tend to under-estimate the level of uncertainty (e.g., NRC 1997). Model 1 may best represent the underlying processes that affect observations (e.g., availability of different age-classes can change over time to different gear types). Therefore, the results presented in subsequent sections are based on Model 1.

Results from Model 9 (average recruitment independent of stock size) are similar to Model 1 in many respects. For example, the 1999 begin-year female spawning biomass levels are quite similar, as are the indications on the fits to the data. Since Model 9 does not have an integrated stock-recruitment relationship, analyses on MSY-related quantities are equivalent to yield-per-recruit analyses. That is, Model 9 configuration is inappropriate to evaluate recruitment-overfishing. For this reason, the level of B_{msy} is quite low and the F_{msy} is quite high. This outcome suggests that, given the assumed natural mortality rate and estimated fishery selectivity pattern, the maximum yield-per-recruit occurs at a much higher fishing mortality rate than has been recently observed.

The effect of attempting to estimate natural mortality for pollock age 3 and older (Model 6) gave values very similar to the default value used (0.298 versus 0.30). Accordingly, there were only minor implications to estimates of 1999 yield values (e.g., $F_{40\%}$ value equal to 998 million t compared to 1.013 for Model 1). Early investigations on information about natural mortality using likelihood profiling methods (evaluating the model for different fixed values of *M*) revealed the trade-off studied by Thompson (1996) between selectivity at older ages and natural mortality rates. In particular, for low values of natural mortality, the EBS shelf survey selectivity became strongly dome-shaped. Since pollock are known to move onto the shelf bottom as they age, this result seemed unrealistic.

Since the stochastic stock-recruitment relationship used here plays a critical role in determining the levels for MSY-related quantities, we examined alternatives. First, a Beverton-Holt stock-recruitment function was fit. Due to the pattern of having several large year-classes come from relatively low spawning biomass levels, the estimate was effectively the same as that specified for Model 9 (average recruitment independent of stock size). Second, in all EBS pollock assessments to date, the 1978 year-class has been the highest on record. This year-class was spawned from a relatively low parental biomass level. Consequently, we examined the effect of ignoring this year-class' influence on the expected stock-recruitment curve. This is specified under Model 7. Finally, as in last year's assessment, we evaluate the influence of surface advection of larvae on year-class strength (Model 8).

Models 7 and 8 had slightly lower values for 1999 F_{msy} harvest levels with Model 7 being the lowest value at 1.73 million tons (Table 1.11). This indicates that the 1978 year-class influences the degree stock productivity, but only slightly. Also, the level of uncertainty was higher for Models 7 and 8 compared to Model 1.

1.6. Results

Several key results have been summarized in Tables 1.10 & 1.11. The difference in the current and projected age structure for Model 1 relative to last year's assessment (based on last year's Model 4) is shown in Fig. 1.15. This figure shows very similar predictions in absolute numbers at age for the near term, despite the addition of a different catch trajectory and a downward trend in bottom trawl survey biomass. The slight decrease in estimated numbers at age may be attributed to the declining trend in survey abundance (the current survey is 27% lower than the 1997 estimate). Also, the 1992 year-class is estimated to be slightly higher than last year, presumably due to the predominance of that year-class in the 1998 EBS bottom-trawl survey (e.g., Fig. 1.13b).

The estimated Model 1 selectivity pattern for the fishery shows how estimates of selectivity change over time (Fig. 1.16). An example of how well the model fit the fishery age-composition data is given in Fig. 1.17. Selectivity was allowed to vary slightly over time for both surveys. This was done to account for potential changes in fish distribution rather than to question the standard survey methods employed. For example, it seems reasonable to assume that the presence of 1-year-olds available to the bottom-trawl gear on the shelf might be variable, even when the abundance is the same. In fact, the variability in estimates of selectivity for the bottom trawl survey gear is minor (Fig. 1.18). Not surprisingly, this variability allowed for good fits to the age composition estimates (Fig. 1.19).

The Model 1 fit and estimated selectivity for the EIT survey data shows a failure to estimate the 1979 total age 1+ numbers very well. This is due to the large number of 1 and 2-year old fish apparent in the survey that year (Fig. 1.20). This is illustrated in the model fit to the survey age composition data (Fig. 1.21). The proportions at age observed in the survey are generally consistent with what appeared later in the bottom-trawl survey and fishery. Estimated numbers-at-age for Model 1 are presented in Table 1.12 and estimated catch-at-age presented in Table 1.13.

1.6.1. Abundance and exploitation trends

The eastern Bering Sea bottom trawl survey estimates exhibited an increasing trend during the 1980s, were relatively stable from 1991 to 1995, and decreased sharply in 1996 but rose slightly in 1997. This may be due, in part, to age-related distribution changes within the pollock population. Results from combined bottom trawl and EIT surveys, which more fully sample the population, have shown that older pollock are more vulnerable to bottom trawls than younger pollock (Table 1.5).

In 1979 when a large proportion of the population consisted of age groups 1 to 3, most of the pollock were located in mid-water. However, as the population, composed primarily of 1978 and 1982 year-classes, aged through the 1980s, the bottom trawl proportion increased. The proportion in the bottom trawl decreased in 1994 due to the large numbers of 1989 and 1992 year-class pollock in mid-water. The ratio of demersal to pelagic pollock remained similar between 1994 and 1997, with between 60-64% of the biomass distributed near bottom.

Current exploitable biomass estimates (ages 3 and older) derived from catch-age models and survey abundance estimates suggest that the abundance of eastern Bering Sea pollock remained at a fairly high level from 1982-88, with estimates ranging from 13 to 15 million t. Peak biomass occurred in 1985 and declined to about 7 million t in 1991, then increased to over 9 million t by 1993. Results from the model indicate that the biomass for ages three years and older is about 5.4 million t in the beginning of 1998.

Historically, biomass levels have increase from 1979 to the mid-1980's due to the strong 1978 and relatively strong 1982 and 1984 year-classes recruiting to the fishable population (Table 1.14, Fig. 1.22). From 1985-86 to 1991 the fishable stock declined as these above average year-classes decreased in abundance with age and were replaced by weaker year-classes. In 1992 an upturn in abundance began with the recruitment of a strong 1989 year-class, but biomass has been decreasing since 1993, the year-classes entering the fishery in recent years have been weak except for the 1992 year-class. An increase in abundance is expected in future years as apparently above average 1995 and 1996 year-classes recruit to the exploitable population. Retrospectively, compared with last year's assessment the recent estimates of age 3+ pollock biomass are lower in the current assessment

(Table 1.14). Again, this may be attributed to the 1998 bottom trawl survey estimate being lower than in recent years.

The abundance and exploitation pattern estimated from Model 1 shows that the spawning exploitation rate (SER, defined as the percent removal of spawning-aged females in any given year) has averaged about 18% in the past 10 years. This compares to an overall average SER of 22.5% (1964 - 1998) and 34% for the period 1971-1980 (Fig. 1.23). The observed variation in pollock abundance is primarily due to natural variation in the survival of individual year-classes. These values of SER are relatively low compared to the estimates at the MSY level (~30-34%).

1.6.2. Recruitment

Recruitment of pollock is highly variable and difficult to predict. It is becoming clear that there is a great deal of variation in the distribution of pre-recruit pollock, both in depth and geographic area. To some extent, our approach takes this into account since age 1 fish are included in our model and data from both the EIT and bottom trawl survey are used. Previously, the primary measure of pollock recruitment has been the relative abundance of age 1 pollock (or pollock smaller than 20 cm when age data are unavailable) in the annual eastern Bering Sea bottom-trawl survey. Also, bottom-trawl survey estimates of age 1 recruitment, when regressed against age 3 pollock estimates from catch-age models, indicate a linear relationship. This had been used to project age 3 numbers in population forecasts. Our method does not require external regressions since the necessary accounting is done explicitly, within a standard age-structured model. The key advantage in our approach is that the observation and process errors are maintained and their effect can be evaluated.

It appears that the annual bottom trawl survey does not fully cover the distribution of age 1 pollock. This is especially evident for the 1989 year-class which the survey found to be slightly below average, but upon recruitment to the fishery was a very strong year-class. It appears that a significant amount of this year-class was distributed in the Russian EEZ—beyond the standard survey area—or unavailable to bottom trawl gear (perhaps in mid-water). In 1996 Russian scientists reported the 1995 year-class to be strong, but it appeared to be below average in the U. S. survey. However, in the 1997 EIT survey the 1995 year-class was abundant adjacent to the Russian EEZ.

The coefficient of variation or “CV” (reflecting uncertainty) on the strength of the 1996 year-class is about 39% for Model 1. The 1996 year-class appears to be moderately strong. However, the 95% confidence bounds for the 1996 year-class slightly overlaps with the mean recruitment for all years since 1964 (Fig. 1.24). Adding the effect of the surface currents on recruitment success appears to be a plausible mechanism but it does not reduce the degree of uncertainty in the magnitude of the 1996 year-class. This is due to the fact that we now have 3 direct observations of this year class from survey data: the EIT survey conducted in 1997 and the bottom trawl surveys in 1997 and 1998. Further refinements and development of jack-knife testing procedures for the recruitment hypotheses are ongoing at the AFSC.

1.7. Projections and harvest alternatives

Currently, the biomass of eastern Bering Sea pollock appears to be below the 6.0 million t level previously considered an estimate of B_{msy}. The level of production at that stock size had been estimated to be about 1.8 million t of yield. In the current analyses we estimate MSY-related quantities using female spawning biomass as an index of stock size (previous studies used total number of adults), average fishery selectivity in the past 10 years (previously, knife-edged recruitment was assumed), and an updated estimate of stock-recruitment relationship. The current estimate gives very similar values for MSY (1.9 million tons for Model 1). The overall B_{msy} level is a bit different where under an equilibrium age-structure, the B_{msy} value in mature female spawning biomass translates to an age 3+ biomass of about 5.2 million tons. Presumably this is due to the fact that selectivity is shifted towards older pollock compared to the previous analyses which assumed knife-edged values at age 3.

The projected spawning biomass levels (fishing at F_{msy}) compared to historical estimates and the estimates of B_{msy} are shown in Figure 1.25. This depicts that current spawning biomass is nearly at the target B_{msy} value but that due to the current age-structure of the population, will drop slightly until the 1996 year-class matures and significantly contributes to the spawning population around year 2003 (Table 1.15).

Estimates of uncertainty in the 1999 projected yield based on alternative (unadjusted) fishing mortality rates are depicted in Figure 1.26. This indicates that at $F_{40\%}$ (unadjusted) the harvest in 1999 would be about 1.01 million t while the point estimate for F_{msy} would be substantially higher (1.86 million t).

For 1999 ABC alternatives based on the $F_{40\%}$ and F_{msy} are **1.01** and **1.45** million tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value) as shown in Table 1.11 for Model 1. The harmonic mean value for F_{msy} computations are somewhat different than the procedure outlined in tier 1 of Ammendment 44. That is, the harmonic mean is applied to the estimated pdf for the 1999 yield under F_{msy} rather than first finding the harmonic mean of F_{msy} and applying its value say to the maximum likelihood estimate for 1999 stock size. The former method results in somewhat lower ABC values since uncertainty in both the F_{msy} value and future stock size are both considered. For example, the harmonic mean of F_{msy} is estimated to be 0.643, which if applied to Model 1 point estimate of stock size gives a 1999 harvest level of 1.575 million tons.

The 1999 overfishing level (OFL) alternatives for the reference model are **1.55** and **1.897** corresponding to $F_{30\%}$ and F_{msy} (arithmetic mean). A 1999 harvest level of 1 million tons has only about 15% chance of being greater than the corresponding 1999 F_{msy} harvest level. Harvest of 1 million t in 1999 is also somewhat lower than the risk-averse strategy advised under Tier 1 in Amendment 44 where the harmonic mean of F_{msy} is recommended.

If Ammendment 44 tier 3 is to be used, there are issues related to computation of $B_{40\%}$. It's value depends on the long-term expected recruitment for the stock. So far, our default estimate for this computation has been to use the median value of recruitment estimated over the entire time series. Alternative estimates prove to be sensitive to this as shown in Table 1.16. The 1999 harvest under the tier 3b drops to 910 thousand t when the recruitment is based on the long-term average value (including the 1978 year-class). The $B_{40\%}$ value using the entire time series is much greater than the estimate of B_{msy} (2.24 million tons compared to 1.74). Perhaps the more appropriate segment of the time series to use is for the past 10 years (including the strong 1989 year-class) which would give an adjusted 1999 ABC level of 978 thousand tons.

Further spawning stock considerations

Examinations of the effect of alternative harvest levels on female spawning biomass and yield are shown in Figures 1.27 and 1.28, respectively. Fishing at the (unadjusted) $F_{40\%}$ indicates an increase in female spawning biomass whereas for the unadjusted F_{msy}, the spawning biomass level is stable at around the current level. Since there still exists a large amount of uncertainty in the magnitude of the 1996 year-class, discussion of future expectations of spawning stock size must consider this level of uncertainty. That is, while we expect that fishing under an F_{msy} harvest level we will have better than even odds (50% probability) of having the spawning biomass greater than the B_{msy} level, there still is a 25% chance that the spawning biomass in the year 2003 will be less than 1.5 million tons (Fig. 1.29).

1.8. Other considerations

1.8.1. Gear changes

It has become common knowledge that several (most) vessels fishing for pollock have changed their nets to have a square mesh panel designed to reduce the take of under-sized fish. This may change the effective selectivity of the gear in a predictable way. While our approach allows for changes in selectivity, further analyses on this effect may be warranted.

1.8.2. Stock structure

Recent information obtained from U.S. and Russian EIT surveys in the Bering Sea indicate that the eastern Bering Sea pollock stock has a distribution that is continuous into the Russian EEZ. The 1994 Miller Freeman EIT survey found a biologically-similar distribution of pollock inhabiting the region from the Pribilofs to Cape Navarin. In 1996 and 1997, each country surveyed their own EEZ and again results show the distribution of pollock in the northwest portion of the U.S. EEZ continuing across the Convention Line into the Cape Navarin region. Historical Russian data also suggest that pollock in the Russian EEZ east of 176 E are predominantly of eastern Bering Sea origin (Shuntov et al 1993). However, current Russian opinion is that an oceanographic regime shift has recently occurred in the northern Bering Sea resulting in a far smaller fraction (5%) of EBS pollock in the Navarin region.

Further, it is thought that most of the juvenile fish in this area will recruit to the eastern Bering Sea spawning stock as adults. This was evident with the 1989 year-class, which was found in relatively low abundance in the US EEZ, but was found to be very abundant in the Russian EEZ early in life. The 1989 year-class subsequently was found to be the one of the largest year-classes produced within the eastern Bering Sea.

The problem of a straddling pollock stock is that the western Bering Sea pollock stock is currently at a low level of abundance. With the decease in western Bering Sea pollock abundance Russian and joint-venture fishing effort have increased in the Russian EEZ northern area. If significant harvests of juvenile pollock that will recruit to the eastern Bering Sea exploitable population occur in the Russian EEZ, then there may be a reduction in the exploitable biomass and yield in the US EEZ. The following table contains the reported catch for the Navarin area (176E to the Convention Line) received from TINRO, the catch as a percentage of the total western Bering Sea catch, and the age composition of the catch for ages 1,2,3, and 4 and older:

Year	Navarin Catch 1,000's tons	Percent Russian Bering Sea catch	**Catch at age** 0	1	2	3	4+
1976	467	85%	0%	0%	5%	78%	18%
1977	180	68%	0%	0%	3%	13%	84%
1978	254	61%	0%	3%	6%	21%	91%
1979	285	52%	14%	23%	55%	6%	3%
1980	620	49%	0%	1%	15%	78%	7%
1981	900	75%	0%	0%	6%	39%	55%
1982	804	64%	0%	1%	10%	23%	67%
1983	722	65%	8%	30%	3%	21%	39%
1984	503	50%	0%	6%	0%	2%	95%
1985	488	58%	0%	44%	31%	14%	11%
1986	570	69%	0%	8%	45%	14%	33%
1987	463	63%	0%	0%	6%	28%	67%
1988	852	76%	0%	1%	7%	22%	70%
1989	684	70%					
1990	232	53%					
1991	178	39%					
1992	316	53%					
1993	389	46%	0%	2%	7%	11%	80%
1994	178	43%	0%	0%	11%	17%	70%
1995	320	98%	0%	0%	16%	22%	62%
1996	753	95%					
1997	680	93%					
1998	700*						
Avg.	493	62%	1%	7%	14%	26%	53%

* Preliminary

Currently, NMFS is collaborating with scientists at the University of Washington in using micro-satellite DNA methods for evaluating the genetic composition of pollock from diverse regions. These methods are powerful and provide promise for a clearer understanding of stock structure issues.

1.8.3. Steller sea lions and the pollock fishery

The western stock of Steller sea lions (defined as west of 144°W) is currently listed as endangered under the Endangered Species Act, and had been listed as threatened since 1990. In 1991-92, 10 nm annual trawl exclusion zones were established around all rookeries west of 150°W; in 1992-93, 20 nm trawl exclusion zones were established around 6 rookeries in the eastern Aleutian Islands that are operational only during the BSAI pollock A-season. In 1993, NMFS designated Steller sea lion critical habitat, which includes a 20 nm aquatic zone around all rookeries and major haulouts west of 144°W, and three foraging areas, one of which is located in the southeastern Bering Sea from the Islands of Four Mountains to Unimak Pass. Sea lion food habits data collected in the Gulf of Alaska and the Bering Sea revealed that pollock has been the most common food item of adults and juveniles (NMFS 1995).

Temporal and spatial distribution of bsai pollock fisheries

In the BSAI region prior to 1987 (when the spawning assemblage near Bogoslof Island was first exploited), the pollock fishery was conducted primarily in spring and summer (April-September) when about 70-80% of the landings were taken (Fig. 1.30). Since 1987, however, the proportion caught during fall and winter (September-March) increased to between 35-65% as the fishery targeted the higher-priced roe-bearing fish available in winter. Beginning in 1990, the BSAI annual pollock TAC was divided into an "A", or roe season from January to mid-April which initially received 40% of the TAC, and a "B" season beginning in June and lasting until the TAC was reached (BSAI FMP Amendment 14). This measure, while ensuring sufficient pollock TAC for the "B" season, also increased the first quarter's proportion of the annual pollock catch. The “A” season allocation was increased to 45% in 1993 and has remained at that level since. The starting date for the “B” season was also moved to August 15 in 1993 and then to September 1 beginning in 1996.

Increases in the proportions of the annual regional pollock TAC caught in Steller sea lion critical habitat in the BSAI and GOA occurred simultaneously with the exploitation of spawning concentrations of pollock near Bogoslof Island in 1987 (Fig. 1.31). In the BSAI, the percentage caught within critical habitat increased from between 5-20% in the late 1960s to 15-30% from 1971-86. Actual removals mirrored the total catch during this period and peaked at over 500,000 mt in 1971 and 1972, before decreasing to between 200,000 and 300,000 mt from 1977-86. From 1987-95, however, both the catch tonnage and percentage of annual removals of pollock from critical habitat increased over 3-fold to over 800,000 mt and 60%, respectively. This shift resulted from increasing pollock fishery effort in fall and winter (when pollock are more concentrated within critical habitat). Also the fleet composition shifted from a more mobile processing fleet (e.g., foreign factory trawlers) to catcher-vessels dependent on shore-based processors. These catcher vessels in turn are more dependent on coastal fishing areas located within critical habitat.

The recent increase in BSAI critical habitat catches has occurred principally during the A-season (January-March), as evidenced by the high recent removals (between 250,000 and 550,000 mt) and percentage of effort (between 50-90%) from critical habitat from 1992-97. Recent B-season effort distribution has shown movement out of critical habitat during the summer. Since 1992, catches of pollock from critical habitat during the B-season have declined from about 350,000-400,000 mt to 250,000 mt, while the percentages have declined from about 50% to 40% of total B-season removals.

Recent pollock fishery distribution patterns suggest that interactions with sea lions in critical habitats are ongoing despite the partitioning that was achieved in the vicinity of rookeries with the establishment of trawl exclusion zones. In the BSAI, where there is only broad regional allocation of the pollock quota between the eastern Bering Sea and Aleutian Islands management areas, the creation of 10 and 20 nmi trawl exclusion zones did not constrain landings from important sea lion habitats. Pollock removals from sea lion habitats began increasing prior to 1991-93, and it is not known how much the sea lion protective measures may have reduced the rate of increase had they not been enacted. It must be noted, however, that the areas within the existing trawl exclusion zones were not heavily fished prior to their creation. From 1984-1991 the annual percentage of pollock caught within these areas ranged only from 1-7%.

Estimating area-specific pollock harvest rates

There are data available to estimate area-specific pollock harvest rates on the eastern Bering sea (EBS) shelf during summer. Summer bottom trawl surveys have been conducted annually on the EBS shelf, but these surveys only sample the demersal fraction of the pollock population and do not provide estimates of the pelagic portion. Hydroacoustic surveys provide estimates of pelagic pollock abundance, and have been conducted on the EBS shelf in the summers of 1979, 1982, 1985, 1988, 1991, 1994, 1996, and 1997. Combining the results of the annual bottom trawl surveys and trienniel hydroacoustic surveys yields estimates of the distribution and abundance of the entire pollock population on the EBS shelf in summer.

A spatial analysis of B-season pollock harvest rates was conducted by estimating pollock abundances and catches in three areas and four years. The three areas chosen were: (1) the Catcher Vessel Operational Area (CVOA; nearly equivalent to Steller sea lion critical habitat with regard to pollock catch distribution); (2) east of 170°W outside of the CVOA; and (3) west of 170°W. The years 1991, 1994, 1996, and 1997 were chosen because combined bottom trawl-hydroacoustic surveys of the pollock population were conducted in the summers of each of these years. The following method was used to calculate area-specific harvest rates:

- The distribution of survey estimates of age 3+ pollock biomass (30+ cm in length) in each area and year was used to apportion the stock assessment model (Wespestad et al. 1997) estimate of total eastern Bering Sea age 3+ biomass by area and year. This yielded estimates of age 3+ pollock biomass by area for each of the 4 years.

- Observer estimates of B-season pollock catch distribution by sector (offshore, mothership, and inshore), area, and year were used to apportion the blend estimates of B-season pollock catch by sector and year to each area. This yielded estimates of B-season pollock catch (almost entirely composed of pollock age 3 years and older) by area for each of the 4 years.

- Harvest rates were calculated using the ratio of catch to biomass by area.

Harvest rates of age 3+ pollock were higher in the CVOA than in either of the other two areas in the eastern Bering Sea (Fig. 1.32). For each of the four years, harvest rates in the CVOA ranged from a low of 15% in 1994 to 49% in 1997, while in the other two areas, only one of the eight annual harvest rate estimates was greater than 10% and four were 5% or less. Furthermore, data suggest that harvest rates within the CVOA increased in 1996 and 1997 (when they were 29% and 49%, respectively) relative to 1991 and 1994 (when they were 26% and 15%, respectively). Total eastern Bering Sea survey/model age 3+ pollock biomass declined 38% from 1994 to 1997, but this decline was not evenly dispersed among each of the three areas. The decline was steepest in the CVOA, where pollock biomass declined 81% from 1994 to 1997, while in the other areas east and west of 170°, the decline was only 30% and 26%, respectively.

In 1993, NMFS conducted an EIT survey near the end of the A-season from March 6-12. The survey covered the ice-free portion of the southeastern Bering Sea shelf (approximately 24,000 sq. nm.) from Unimak Island to the Pribilof Islands and provided a midwater estimate of 2.292 million tons of pollock. Based on this information, it appears that in 1993 the impact of the fishery during this season was about equal to the long-term exploitation rate. I.e., adding the 480 thousand tons caught during the A-season in 1993 to the estimate of 2.292 million tons gives a crude estimate of harvest rate equal to about 17% of the stock within the survey area. This suggests that for the one year when data were available, the impact of A-season fishery on depletion within the spawning area was moderate compared to the overall stock-harvest rate recommendations.

1.9. Summary

Summary results are given in Table 1.17.

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1.12. Tables

Table 1.1 Catch from the eastern Bering Sea by area, the Aleutian Islands and the Bogoslof Island area, 1979-95.

	Eastern Bering Sea			Aleutians	Donut Hole	Bogoslof I.
Year	Southeast	Northwest	Total			
1979	368,848	566,866	935,714	9,504		
1980	437,253	521,027	958,280	58,156		
1981	714,584	258,918	973,502	55,516		
1982	713,912	242,052	955,964	57,978		
1983	687,504	293,946	981,450	59,026		
1984	442,733	649,322	1,092,055	81,834	181,200	
1985	604,465	535,211	1,139,676	58,730	363,400	
1986	594,997	546,996	1,141,993	46,641	1,039,800	
1987	529,461	329,955	859,416	28,720	1,326,300	377,436
1988	931,812	296,909	1,228,721	30,000	1,395,900	87,813
1989	904,201	325,399	1,229,600	15,531	1,447,600	36,073
1990	640,511	814,682	1,455,193	79,025	917,400	151,672
1991	712,206	505,095	1,217,301	78,649	293,400	264,760
1992	663,457	500,983	1,164,440	48,745	10,000	160
1993	1,095,314	231,287	1,326,601	57,132	1,957	886
1994	1,183,360	180,098	1,363,458	58,637	NA	566
1995	1,170,828	91,939	1,262,766	64,429	trace	264
1996	1,086,840	105,938	1,192,778	29,062	trace	387
1997			1,112,810	25,478	trace	168
1998						

1979-1989 data are from Pacfin.
1990-1995 data are from NMFS Alaska Regional Office, includes discards.

Table 1.2. Estimated retained, discarded, and percent discarded of total catch in the Aleutians, Northwest and Southeastern Bering Sea, 1990-1996.

Area	Year	Catch Retained	Discard	Total	Discard Percentage
	1990				
Southeast (51)		582,660	57,851	640,511	
Northwest (52)		764,369	50,313	814,682	
Aleutians		69,682	9,343	79,025	
Total		1,416,711	117,507	1,534,218	7.7%
	1991				
Southeast (51)		614,889	97,317	712,206	
Northwest (52)		458,610	46,485	505,095	
Aleutians		73,608	5,041	78,649	
Bogoslof		245,467	19,293	264,760	
Total		1,318,966	163,095	1,482,061	11.0%
	1992				
Southeast (51)		600,861	62,596	663,457	
Northwest (52)		445,811	55,172	500,983	
Aleutians		45,246	3,498	48,745	
Total		1,091,919	121,266	1,213,185	10.0%
	1993				
Southeast (51)		1,011,020	84,294	1,095,314	
Northwest (52)		205,495	25,792	231,287	
Aleutians		55,399	1,733	57,132	
Total		1,271,914	111819	1,383,732	8.1%
	1994				
Southeast (51)		1,091,547	91,813	1,183,360	
Northwest (52)		164,020	16,078	180,098	
Aleutians		57,325	1,311	58,637	
Total		1,312,892	109,202	1,422,094	7.7%
	1995				
Southeast (51)		1,083,381	87,447	1,183,360	
Northwest (52)		82,226	9,713	91,939	
Aleutians		63,047	1,382	64,429	
Total		1,228,654	98,542	1,339,728	7.4%
	1996				
Southeast (51)		1,015,473	71,367	1,086,840	
Northwest (52)		101,100	4,838	105,938	
Aleutians		28,067	994	29,062	
Total		1,145,133	77,206	1,222,339	6.3%
	1997				
Southeast (51)		749,007	71,043	820,050	
Northwest (52)		281,986	22,557	304,543	
Aleutians		25,323	617	25,940	
Total		1,056,316	94,217	1,150,533	8.2%

Table 1.3. Eastern Bering Sea walleye pollock catch by age in numbers (millions), 1979-1997.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total
1979	101.4	543.2	720.0	420.2	392.6	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	0.5	2567.3
1980	9.8	462.4	823.3	443.5	252.2	211.0	83.7	37.6	21.8	23.9	25.5	15.9	7.7	2.5	2420.7
1981	0.6	72.2	1012.9	638.0	227.0	102.9	51.7	29.6	16.1	9.4	7.5	4.6	1.5	0.6	2174.6
1982	4.8	25.3	161.4	1172.4	422.4	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	0.7	2003.7
1983	5.1	118.6	157.8	313.0	817.0	218.3	41.4	24.7	19.8	11.1	7.6	4.9	3.5	1.7	1744.5
1984	2.1	45.8	88.6	430.8	491.9	654.3	133.9	35.6	25.1	15.7	7.1	2.5	2.9	1.7	1938.0
1985	2.7	55.3	382.2	122.1	366.7	322.3	444.3	112.8	36.7	25.9	24.9	10.7	9.4	4.0	1919.9
1986	3.1	86.0	92.3	748.5	214.1	378.1	221.9	214.2	59.7	15.2	3.3	2.6	0.3	1.2	2040.4
1987	0.0	19.9	112.2	78.0	415.8	139.6	123.2	91.2	248.6	54.4	38.9	21.6	29.1	6.1	1378.5
1988	0.0	10.7	455.2	422.8	252.8	545.9	225.4	105.2	39.3	97.1	18.3	10.2	3.8	5.5	2192.2
1989	0.0	4.8	55.3	149.5	452.6	167.3	574.1	96.6	104.1	32.5	129.5	10.9	4.0	2.6	1783.8
1990	1.3	33.2	57.3	220.7	201.8	480.3	129.9	370.4	66.1	102.5	9.1	60.4	8.5	4.7	1746.2
1991	1.0	60.9	40.7	85.4	141.5	156.9	396.4	51.6	217.1	22.1	114.7	15.2	74.4	60.9	1438.8
1992	0.0	79.0	721.7	143.5	98.1	125.0	145.4	276.8	109.3	165.4	59.4	50.2	14.2	91.0	2079.0
1993	0.1	9.2	275.0	1144.5	103.0	64.3	62.2	53.5	84.9	21.8	34.5	12.6	13.1	26.5	1905.2
1994	0.3	31.5	59.8	383.4	1109.5	180.5	54.9	21.0	13.5	20.1	9.1	10.7	7.6	15.7	1917.5
1995	0.0	0.3	75.3	146.6	398.4	764.7	131.8	34.9	10.9	6.0	15.3	4.4	7.1	11.3	1606.9
1996	0.0	9.5	19.7	43.8	144.9	350.7	486.3	190.4	32.9	14.8	8.9	8.8	4.1	11.3	1326.1
1997	0.1	65.4	32.6	109.7	472.8	289.1	254.6	198.5	62.8	14.2	6.5	5.1	3.1	14.8	1529.3

Table 1.4. Numbers of samples used for lengths (measured) and age determinations (aged) by sex and strata, 1991-1996.

	Strata	1991	1992	1993	1994	1995	1996	1997
Measured males	Aleutians	34,023	33,585	33,052	28,465	21,993	12,336	10,477
	Northwest	126,023	110,487	38,524	28,169	17,909	22,290	58,307
	Southeast A Season	198,835	150,554	122,436	138,338	127,876	148,706	123,385
	Southeast B Season	102,225	134,371	143,420	153,336	175,524	193,832	114,826
Total		461,106	428,997	337,432	348,308	343,302	377,164	306,995
Measured females	Aleutians	14,620	19,079	21,055	16,125	16,475	8,792	9,056
	Northwest	124,934	114,778	39,985	28,185	19,282	22,144	51,358
	Southeast A Season	184,351	142,016	112,602	146,918	124,000	140,868	102,530
	Southeast B Season	90,056	136,626	135,661	146,540	150,632	149,583	105,999
Total		413,961	412,499	309,303	337,768	310,389	321,387	268,943
Aged males	Aleutians	22	110	81	157	73	86	15
	Northwest	320	179	147	132	123	0	326
	Southeast A Season	373	454	451	200	297	470	431
	Southeast B Season	248	317	475	571	415	442	284
Total		963	1,060	1,154	1,060	908	998	1,056
Aged females	Aleutians	23	121	82	151	105	77	15
	Northwest	340	178	153	142	131	0	326
	Southeast A Season	385	458	478	201	313	451	434
	Southeast B Season	233	332	458	574	392	434	312
Total		981	1,089	1,171	1,068	941	962	1,087

Table 1.5. Biomass (age 1+) of eastern Bering Sea walleye pollock in as estimated by surveys 1979-1998 (millions of tons).

Year	Bottom trawl survey (t)	EIT Survey (t)	EIT Percent age 3+	Total (t)	Near bottom biomass
1979	3.20	7.46	(22%)	10.66	30%
1980	1.00				
1981	2.30				
1982	2.86	4.90	(95%)	7.76	46%
1983	6.24				
1984	4.89				
1985	4.63	4.80	(97%)	9.43	54%
1986	4.90				
1987	5.11				
1988	7.11	4.68	(97%)	11.79	63%
1989	5.93				
1990	7.13				
1991	5.11	1.45	N/A	6.56	79%
1992	4.37				
1993	5.52				
1994	4.98	2.89	(85%)	7.87	64%
1995	5.41				
1996	3.20	2.31	(97%)	5.51	60%
1997	3.03	2.59	(70%)	5.62	54%
1998	2.21				

Table 1.6. Sampling effort of pollock in the EBS based on the NMFS bottom trawl survey 1982-1998.

Year	Number of Hauls	Lengths	Aged
1982	329	40,001	1,611
1983	354	78,033	1,931
1984	355	40,530	1,806
1985	353	48,642	1,913
1986	354	41,101	1,344
1987	342	40,144	1,607
1988	353	40,408	1,173
1989	353	38,926	1,227
1990	352	34,814	1,257
1991	351	43,406	1,083
1992	336	34,024	1,263
1993	355	43,278	1,385
1994	355	38,901	1,141
1995	356	25,673	1,156
1996	355	40,789	1,387
1997	356	35,536	1,193
1998	355	37,673	1,261

Table 1.7. Number of hauls and sample sizes for EBS pollock collected by the EIT surveys.

Year	Stratum	No. Hauls	No. lengths	No. otoliths collected	No. aged
1979	**Total**	25	7,722	NA	2,610
1982	**Total**	48	8,687	NA	2,741
	Midwater, east of St Paul	13	1,725		783
	Midwater, west of St Paul	31	6,689		1,958
	Bottom	4	273		0
1985	**Total** (Legs1 &2)	73	19,872	NA	2,739
1988	**Total**	25	6,619	1,519	1,471
1991	**Total**	62	16,343	2,065	1,663
1994	**Total**	77	21,506	4,973	1,770
	East of 170 W				612
	West of 170 W				1,158
1996	**Total**	57	16,910	1,950	1,926
	East of 170 W				815
	West of 170 W				1,111
1997	**Total**	86	30,535	3,635	2,285
	East of 170 W				936
	West of 170 W				1,349

Table 1.8. Average weights-at-age (kg) by year as used in the model for the fishery and for computing biomass levels for EBS pollock. NOTE: 1998 weight-at-age is treated as the average of values from 1995-1997.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
64-90	0.007	0.170	0.303	0.447	0.589	0.722	0.840	0.942	1.029	1.102	1.163	1.212	1.253	1.286	1.312
91	0.007	0.170	0.277	0.471	0.603	0.722	0.837	0.877	0.996	1.109	1.127	1.194	1.207	1.256	1.244
92	0.007	0.170	0.387	0.454	0.615	0.660	0.745	0.898	0.960	1.151	1.174	1.203	1.132	1.184	1.304
93	0.007	0.170	0.492	0.611	0.657	0.770	0.934	1.078	1.187	1.238	1.385	1.512	1.632	1.587	1.465
94	0.007	0.170	0.398	0.628	0.716	0.731	0.709	0.995	1.287	1.228	1.197	1.329	1.308	1.282	1.282
95	0.007	0.170	0.389	0.505	0.733	0.841	0.854	1.000	1.235	1.314	1.375	1.488	1.402	1.336	1.491
96	0.007	0.170	0.332	0.448	0.717	0.817	0.964	0.966	1.059	1.142	1.371	1.452	1.487	1.679	1.460
97	0.007	0.170	0.326	0.466	0.554	0.747	0.892	1.071	1.085	1.235	1.333	1.422	1.571	1.451	1.419
98	0.007	0.170	0.349	0.473	0.668	0.801	0.903	1.012	1.126	1.231	1.360	1.454	1.486	1.489	1.456

Table 1.9. An evaluation of fits for the models 1-4. Effective N (sample size) computations are as presented in McAlister and Ianelli (1997). See text for model descriptions.

Fits to data sources	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**
Age Composition data									
Effective N Fishery	223	223	223	208	94	223	223	224	224
Effective N Bottom trawl survey	146	146	146	78	77	146	146	146	146
Effective N Hydro acoustic survey	75	75	75	35	35	75	75	75	75
Survey abundance estimates, RMSE*									
Trawl Survey	0.026	0.026	0.026	0.037	0.039	0.026	0.026	0.026	0.026
EIT survey	0.104	0.104	0.104	0.431	0.420	0.104	0.104	0.104	0.104
Recruitment Residuals									
Due to Stock	0.16	0.16	0.16	0.12	0.06	0.16	0.14	0.20	0.15
RMSE Env	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Residual RMSE	0.53	0.53	0.53	0.57	0.65	0.53	0.55	0.48	0.53
Total	0.68	0.68	0.68	0.69	0.71	0.68	0.68	0.68	0.68

*RMSE = $\sqrt{\frac{\sum \ln(obs/pred)^2}{n}}$

Table 1.10. Summary model results. Values in parentheses are coefficients of variation (CV's) of values immediately above. See text for model descriptions.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Stock condition									
1999 Spawning biomass (at time of spawning, Fmsy)	1,585	1,568	1,669	1,381	1,221	1,575	1,591	1,594	1,188
(CV)	(22%)	(22%)	(21%)	(16%)	(18%)	(24%)	(22%)	(22%)	(29%)
B_{msy}	1,738	1,743	1,721	1,747	1,797	1,732	1,777	1,717	739
(CV)	(14%)	(14%)	(15%)	(14%)	(13%)	(15%)	(15%)	(15%)	(17%)
$B_{40\%}$ (based on avg. recruitment 1964-1998	2,236	2,236	2,236	2,195	2,144	2,243	2,234	2,238	2,220
(CV)	(18%)	(18%)	(18%)	(18%)	(18%)	(19%)	(18%)	(18%)	(18%)
1999 spawning biomass / B_{msy}	91%	90%	97%	79%	68%	91%	90%	93%	161%
1999 spawning biomass / $B_{40\%}$	77%	77%	78%	68%	61%	76%	76%	77%	74%
1998 Age 3+ Biomass	5,133	5,133	5,133	4,644	4,160	5,099	5,100	5,127	4,977
Yr 2003 Spawners @ F_{msy}	1,666	1,671	1,662	1,599	1,628	1,659	1,709	1,657	598
	(39%)	(40%)	(36%)	(40%)	(34%)	(40%)	(39%)	(39%)	(45%)
Avg Recruitment (all yrs)	15,808	15,808	15,808	15,796	15,131	15,741	15,769	15,796	15,770
CV Recruitment (process error)	91%	91%	91%	92%	99%	90%	91%	91%	90%
1996 year-class	38,999	38,999	38,999	33,153	30,232	38,632	38,568	39,157	37,349
	(35%)	(35%)	(35%)	(20%)	(19%)	(37%)	(35%)	(36%)	(35%)

Table 1.11. Summary model results relating to yield. See text for model descriptions.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Yield Considerations									
1999 Yield F_{msy}	1,864	1,870	1,734	1,639	1,444	1,849	1,730	1,817	3,247
(CV)	(33%)	(34%)	(31%)	(26%)	(25%)	(35%)	(34%)	(35%)	(26%)
1999 Harmonic Mean F_{msy} Yield	1,449	1,440	1,385	1,392	1,239	1,403	1,330	1,381	2,756
MSY (long-term expectation)	1,897	1,915	1,786	1,911	2,029	1,888	1,816	1,829	1,688
F_{msy}	0.81	0.88	0.44	0.80	0.66	0.81	0.74	0.78	2.29
(CV)	(63%)	(77%)	(49%)	(61%)	(52%)	(64%)	(64%)	(66%)	(27%)
$F_{40\%}$ (average F)	0.369	0.385	0.243	0.369	0.369	0.365	0.369	0.369	0.369
1999 Yield $F_{40\%}$ (adjusted)	1,013	992	985	898	906	998	1,005	1,013	970
Full Selection F's									
F_{msy}	1.168	1.359	0.572	1.168	0.915	1.164	1.064	1.128	3.301
$F_{40\%}$	0.532	0.591	0.314	0.536	0.430	0.526	0.532	0.532	0.533
$F_{35\%}$	0.685	0.771	0.382	0.687	0.538	0.677	0.684	0.684	0.686
$F_{30\%}$	0.903	1.035	0.469	0.901	0.685	0.891	0.901	0.902	0.904

Table 1.12 Estimates of numbers at age for the EBS pollock stock under Model 1 (millions).

Year	1	2	3	4	5	6	7	8	9	10+
1964	2,051	2,272	1,247	246	91	211	110	34	23	159
1965	17,263	832	1,426	864	130	41	97	56	20	120
1966	12,914	7,004	521	980	436	54	18	47	31	90
1967	26,934	5,241	4,398	362	518	195	25	9	27	79
1968	28,127	10,905	3,207	2,539	142	218	89	12	5	58
1969	28,161	11,397	6,727	1,944	1,132	67	110	46	6	37
1970	25,607	11,415	7,055	4,164	914	558	35	59	26	26
1971	7,466	10,150	6,350	3,985	2,318	525	329	21	33	28
1972	7,993	2,936	5,407	3,292	2,027	1,228	288	180	11	31
1973	33,951	3,112	1,483	2,522	1,497	972	616	144	84	18
1974	19,978	13,673	1,671	520	926	570	381	243	52	38
1975	15,808	8,024	6,992	473	156	292	187	126	72	27
1976	14,178	6,375	4,423	2,744	193	66	126	81	51	41
1977	15,663	5,727	3,605	2,117	1,122	77	26	50	30	33
1978	30,826	6,334	3,312	1,873	968	504	35	12	21	26
1979	67,755	12,467	3,664	1,722	858	435	227	16	5	20
1980	26,252	27,477	7,669	2,231	847	352	153	81	5	8
1981	28,052	10,652	17,043	4,885	1,206	398	147	64	33	5
1982	13,485	11,392	6,685	11,570	3,016	687	212	78	34	20
1983	47,578	5,479	7,229	4,795	7,617	1,848	417	129	46	28
1984	11,333	19,335	3,481	5,223	3,241	4,871	1,173	265	80	42
1985	30,262	4,605	12,281	2,512	3,516	2,059	3,068	739	162	68
1986	11,680	12,297	2,919	8,810	1,706	2,289	1,257	1,884	454	120
1987	7,046	4,746	7,796	2,098	6,011	1,118	1,412	780	1,168	310
1988	4,618	2,863	3,015	5,658	1,470	4,101	732	928	512	886
1989	8,801	1,877	1,819	2,171	3,817	947	2,564	428	555	841
1990	49,396	3,577	1,192	1,307	1,456	2,439	586	1,476	252	821
1991	21,820	20,073	2,269	850	854	895	1,441	316	821	593
1992	12,195	8,867	12,734	1,609	550	528	498	707	157	682
1993	21,642	4,954	5,610	8,827	970	309	253	197	286	324
1994	5,948	8,794	3,141	3,962	5,635	588	167	119	95	280
1995	6,496	2,417	5,585	2,274	2,653	3,282	295	75	57	186
1996	13,715	2,640	1,536	4,059	1,549	1,609	1,758	144	38	130
1997	38,999	5,574	1,678	1,119	2,790	961	893	899	77	93
1998	12,498	15,845	3,532	1,207	747	1,660	489	440	450	78
Median	15,808	6,375	3,605	2,231	1,132	570	288	126	51	68
Average	20,757	8,324	4,820	3,015	1,802	1,056	578	311	165	181

Table 1.13. Estimated catch-at-age of EBS pollock for Model 1.

	1	2	3	4	5	6	7	8	9	10+
1964	2	28	70	62	32	71	29	7	3	15
1965	23	12	90	240	50	15	29	12	3	12
1966	15	87	29	244	151	18	5	9	4	8
1967	74	171	843	149	196	65	8	3	7	17
1968	62	287	506	885	45	61	24	3	1	11
1969	55	269	960	621	330	17	27	10	1	6
1970	424	1,179	1,458	900	179	99	6	12	6	6
1971	162	1,353	1,662	1,089	576	118	75	5	10	8
1972	224	496	1,751	1,111	624	346	82	58	4	11
1973	211	398	688	1,118	639	401	252	64	38	8
1974	160	2,198	913	273	470	280	186	129	28	19
1975	84	881	2,886	186	59	106	68	50	29	10
1976	61	584	1,367	1,077	78	26	51	35	23	18
1977	55	430	939	708	387	26	9	19	12	13
1978	108	475	861	625	333	172	12	4	8	10
1979	114	354	567	505	335	201	104	7	2	10
1980	34	603	933	525	270	135	58	32	2	3
1981	21	136	1,234	706	242	98	36	16	9	1
1982	5	44	184	1,117	452	108	33	14	8	6
1983	14	16	154	363	903	230	52	18	8	7
1984	4	61	78	413	401	633	151	40	15	10
1985	11	22	336	181	369	314	456	110	37	22
1986	4	56	76	602	170	332	178	266	99	37
1987	2	15	137	98	412	112	138	76	179	66
1988	1	9	73	439	166	555	135	156	82	146
1989	2	6	47	178	455	135	497	76	94	156
1990	15	15	39	133	214	429	139	320	52	185
1991	7	83	84	93	123	194	424	90	239	193
1992	6	55	708	261	116	163	203	281	63	289
1993	8	22	227	1,058	152	72	80	61	90	114
1994	2	28	62	330	1,047	166	58	37	29	79
1995	2	6	92	158	417	792	88	20	15	44
1996	4	6	22	253	219	351	474	35	9	28
1997	18	28	42	95	478	262	261	255	27	30
1998	6	88	98	113	140	494	155	136	170	28

Table 1.14. Estimates of biomass and coefficients of variation (CV) for Model 1 (current assessment) compared to estimates from the 1997 assessment (columns 4 and 5) for EBS pollock.

Age 3+ Biomass	Current Assessment	CV	1997 Assessment	CV
1964	1,037	30%		
1965	1,227	26%		
1966	1,096	28%		
1967	2,095	22%		
1968	2,510	23%		
1969	3,810	19%		
1970	5,083	15%		
1971	5,813	12%		
1972	5,648	11%		
1973	3,922	14%		
1974	2,342	19%		
1975	3,014	13%		
1976	3,008	13%		
1977	2,894	13%		
1978	2,867	13%	3,244	19%
1979	2,933	15%	3,183	21%
1980	4,294	14%	4,618	19%
1981	8,569	12%	9,190	16%
1982	9,778	12%	10,524	17%
1983	10,705	12%	11,555	16%
1984	10,179	12%	11,028	17%
1985	11,919	11%	12,853	15%
1986	10,913	11%	11,796	16%
1987	11,116	10%	11,952	15%
1988	10,274	10%	11,020	15%
1989	8,546	10%	9,210	16%
1990	6,659	12%	7,240	18%
1991	5,180	13%	5,690	20%
1992	8,294	13%	9,465	21%
1993	10,279	16%	12,086	25%
1994	8,917	18%	10,626	29%
1995	8,680	22%	9,998	32%
1996	6,811	26%	8,142	36%
1997	5,307	31%	6,631	42%
1998	5,133	39%		

Table 1.15 Projections of Model 1 spawning biomass for EBS pollock under different harvest rates (adjusted as appropriate under Amendment 44).

Year	$F_{40\%}$	(Stdev)	$F_{30\%}$	(Stdev)	F_{msy}	(Stdev)
1998	1,616	(704)	(704)	1,616	1,616	(704)
1999	1,720	(872)	(858)	1,640	1,585	(807)
2000	2,015	(1,152)	(1,122)	1,746	1,592	(975)
2001	2,260	(1,381)	(1,334)	1,837	1,615	(1,056)
2002	2,351	(1,565)	(1,512)	1,838	1,590	(1,162)
2003	2,473	(1,800)	(1,729)	1,919	1,666	(1,310)

Table 1.16. Effect of alternative recruitment values used to compute $B_{40\%}$ value and the impact on adjusting the 1999 yield under Model 1 assuming harvests at the $F_{40\%}$ rate. Note that the B_{msy} value for Model 1 is 1,738 thousand t of female spawning biomass.

Recruitment estimate for computing $B_{40\%}$	**Value**	**$B_{40\%}$**	**Adjusted 1999 Yield ($F_{40\%}$)**
Median 1964-1998	15,808	1,703	1,013
Average 1990-1998	16,664	1,795	1,013
Average 1989-1998	19,151	2,063	978
Average 1964-1998 except 1978	19,375	2,088	968
Average 1964-1998	20,757	2,236	910
Harmonic Mean 1964-1998	12,084	1,302	1,013

Table 1.17. Summary results for Model 1, EBS pollock.

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop.F. Mature	0.000	0.004	0.145	0.321	0.421	0.451	0.474	0.482	0.485	0.500	0.500	0.500	0.500	0.500	0.500
Selectivity	0.001	0.012	0.082	0.284	0.501	0.769	1.000	0.925	0.960	0.925	0.986	0.986	0.986	0.986	0.986

	Model 1
1999 Spawning biomass	1,585 t
B_{msy}	1,738 t
$B_{40\%}$	2,063t
Yr 2003 Spawners @ F_{msy}	1,666 t
Yield Considerations	
1999 Harmonic Mean F_{msy} Yield	1,449 t
1999 Yield $F_{40\%}$ (adjusted)	1,013 t
Full Selection F's	
F_{msy}	1.168
$F_{40\%}$	0.532
$F_{35\%}$	0.685
$F_{30\%}$	0.903

1.13. Figures

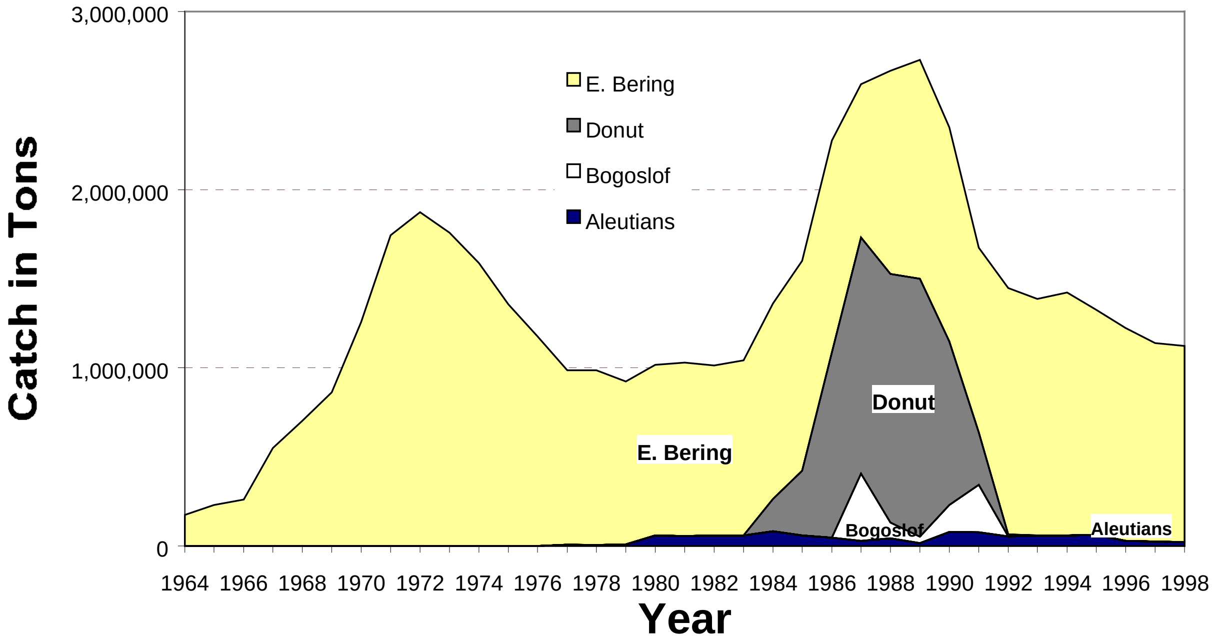


Figure 1.1. Walleye pollock catch in the eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-1997.

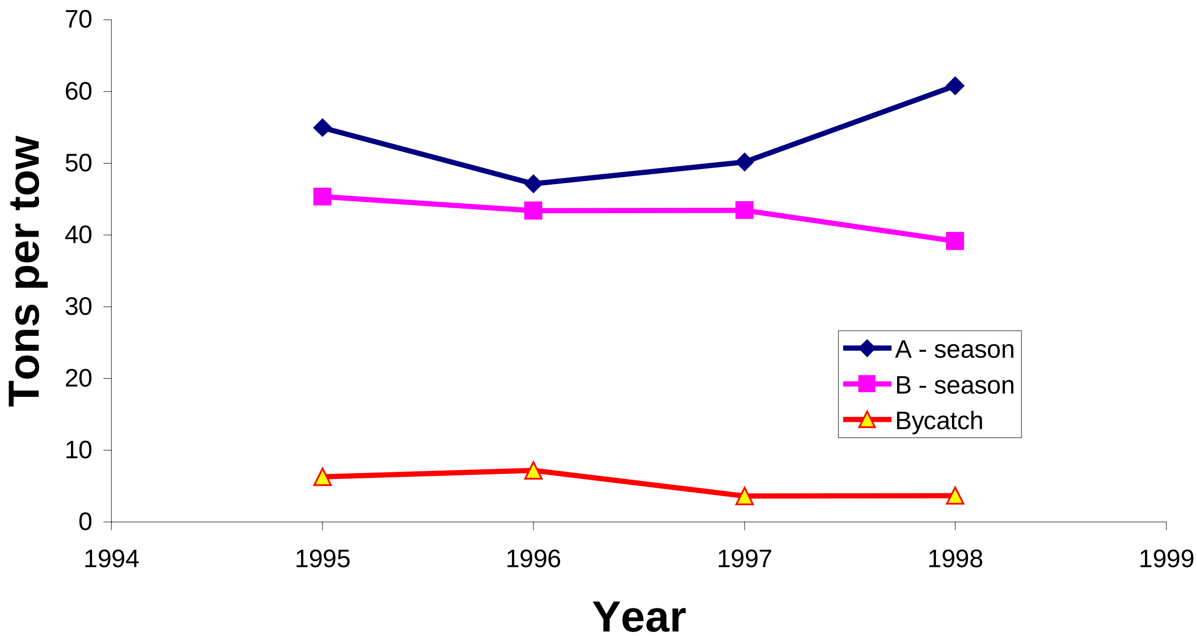


Figure 1.2. Pollock catch-per-tow by season for the eastern Bering Sea, 1995-1998. Note 1998 data are preliminary. Also, catch-per-tow does not account for changes in the duration of each tow (tow duration is typically shorter during the A-season). Bycatch indicates the average offseason catch-per-tow when at least one pollock was observed.

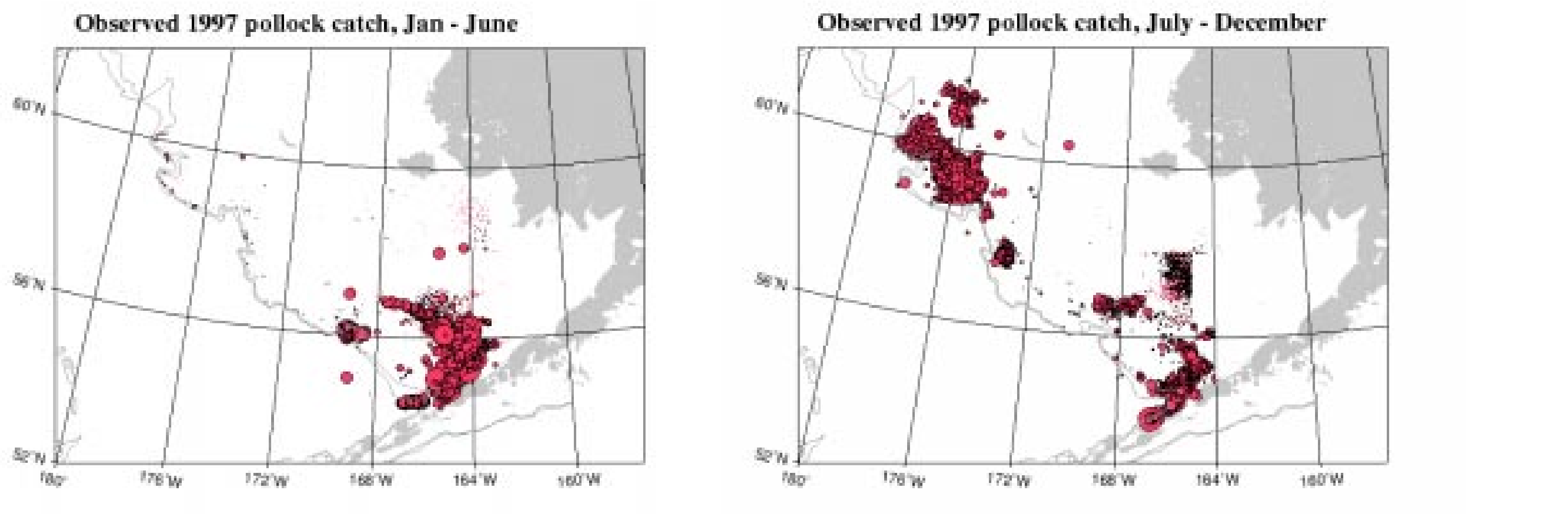


Figure 1.3. Observed locations of the 1997 pollock fishery in the A-(left) and B-(right) seasons on the EBS shelf. The size of the circles approximates nominal catch rates.

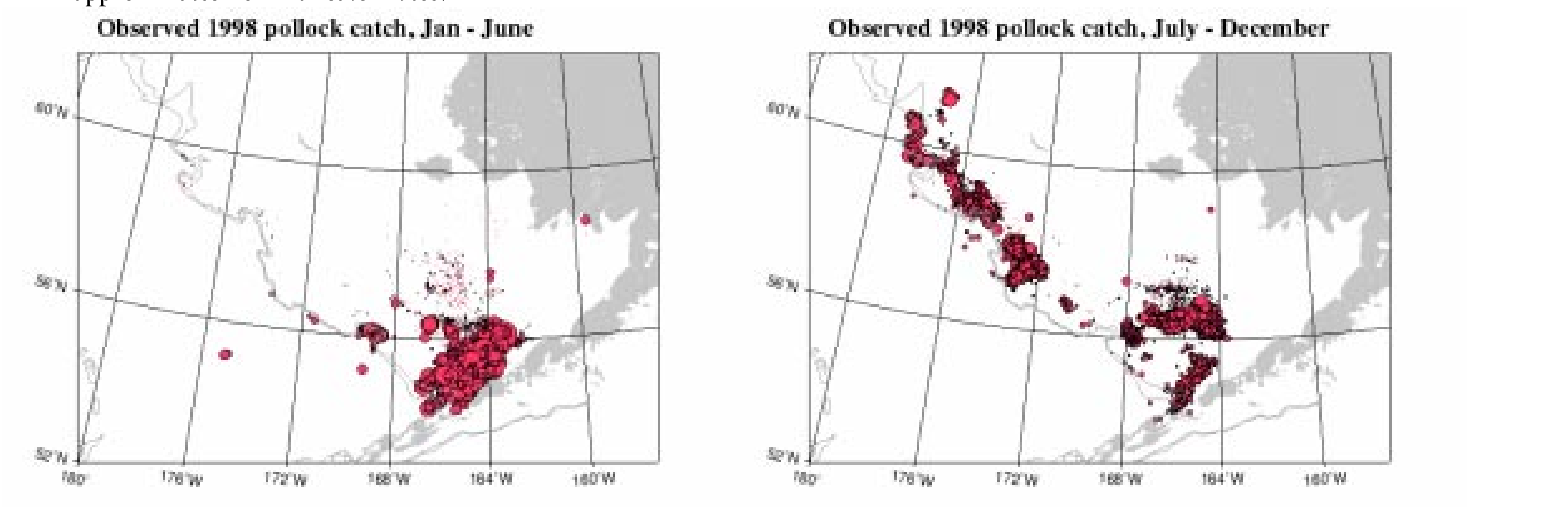


Figure 1.4. Observed locations of the 1998 pollock fishery in the A-(left) and B-(right) seasons on the EBS shelf. The size of the circles approximates nominal catch rates. NOTE: the 1998 data are preliminary.

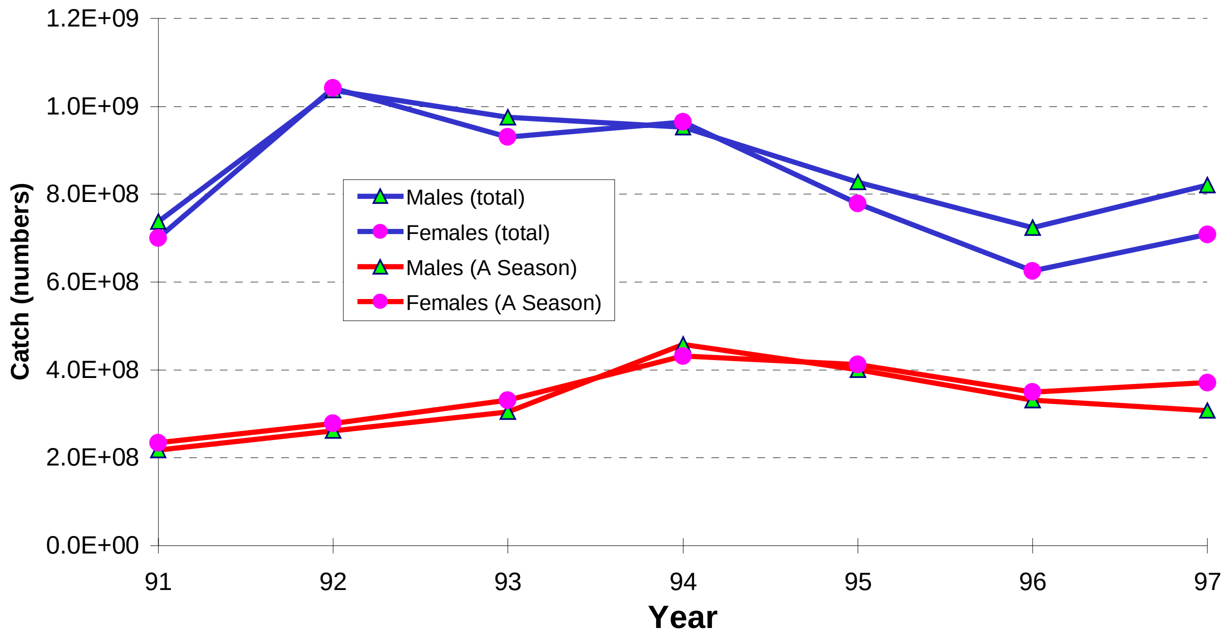


Figure 1.5. Estimate of EBS pollock catch numbers by sex for the “A season” and for the entire fishery, 1991-1997.

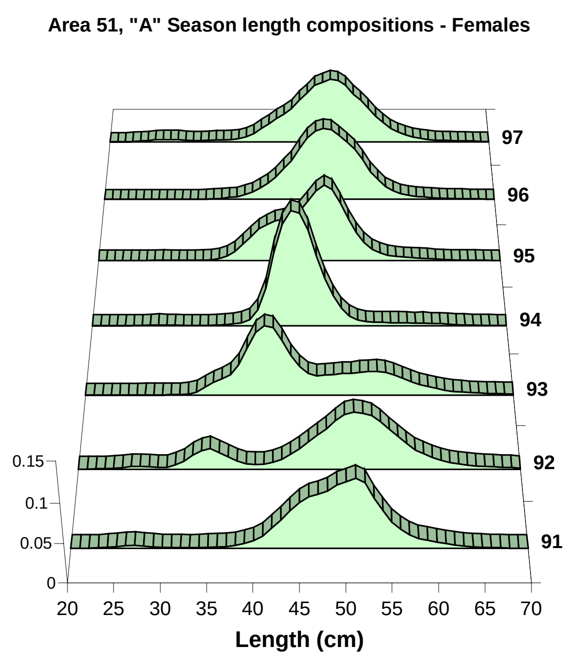


Figure 1.6. Length frequency of EBS female pollock observed in the “A season” for 1991-1997.

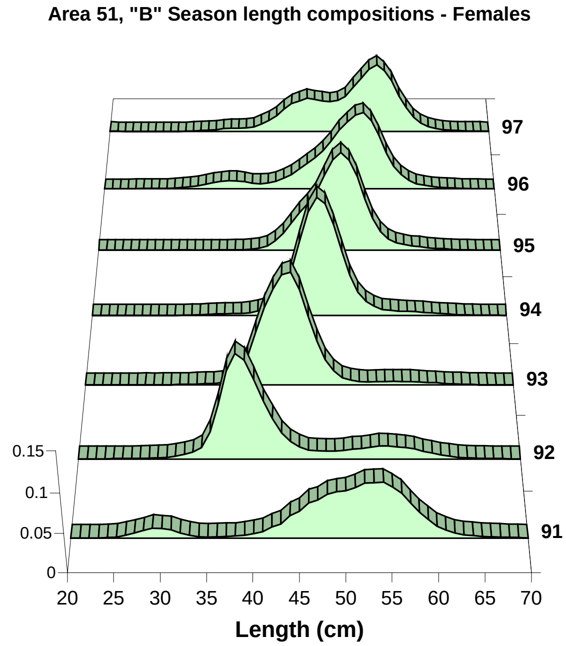


Figure 1.7. Length frequency of EBS female pollock observed in the “A season” for 1991-1997.

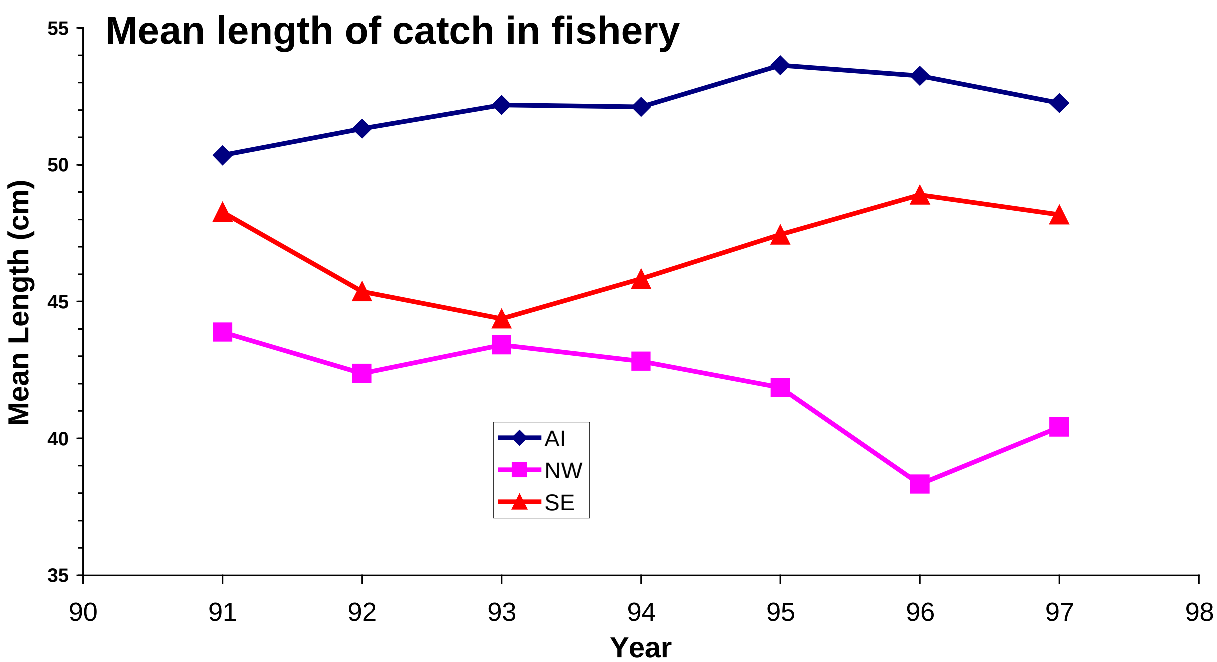


Figure 1.8. Mean length of pollock observed in the fishery by area. AI = Aleutian Islands, NW = northwest portion of the EBS (west of 170W), SE = southeast portion of the EBS (east of 170W).

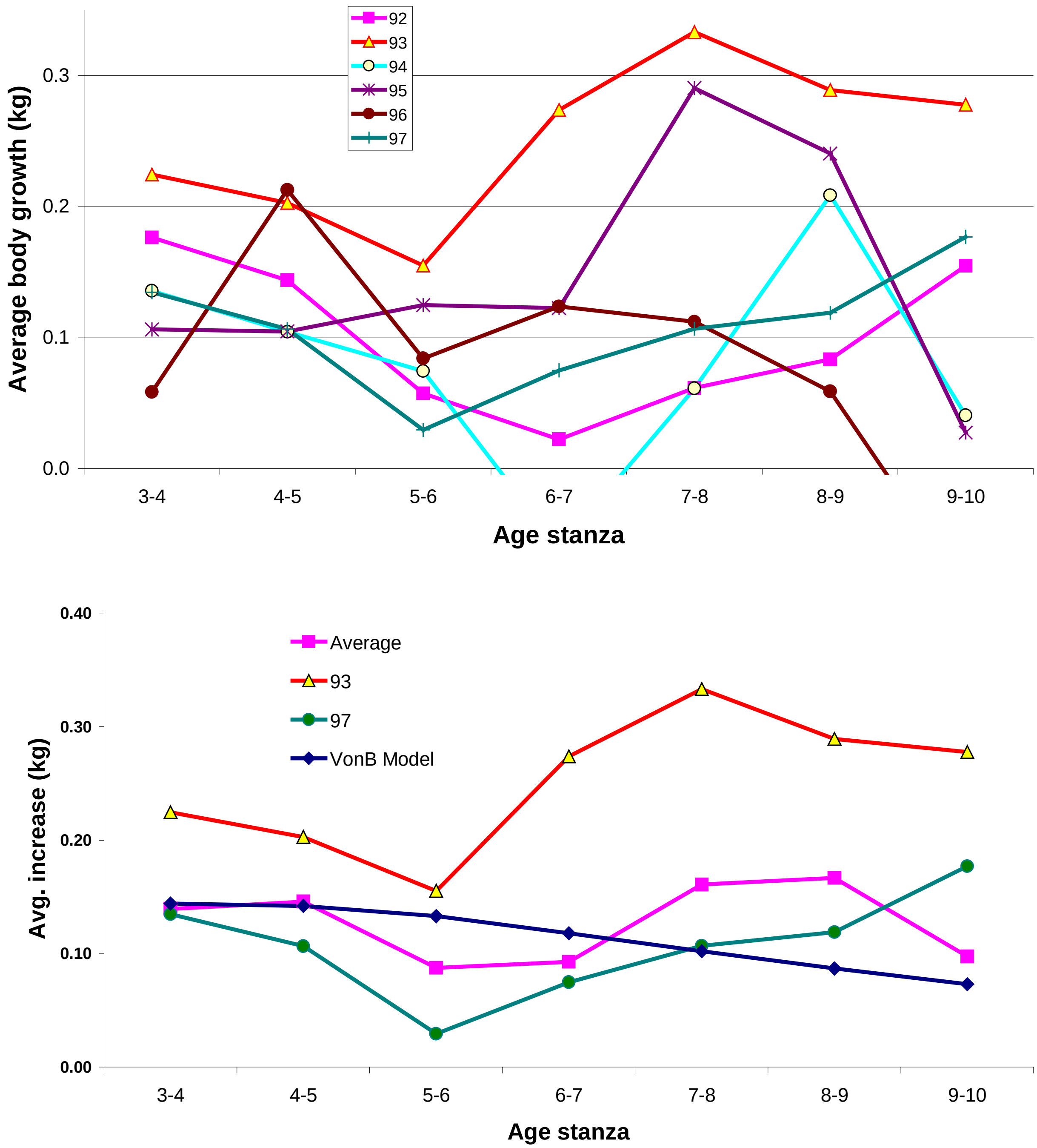


Figure 1.9. EBS pollock average individual growth by year as observed from the fishery. The upper panel shows each year individually while the lower panel shows selected years and the average over years 1991-1997. The VonB model represents expected growth increases from a von Bertalanffy curve.

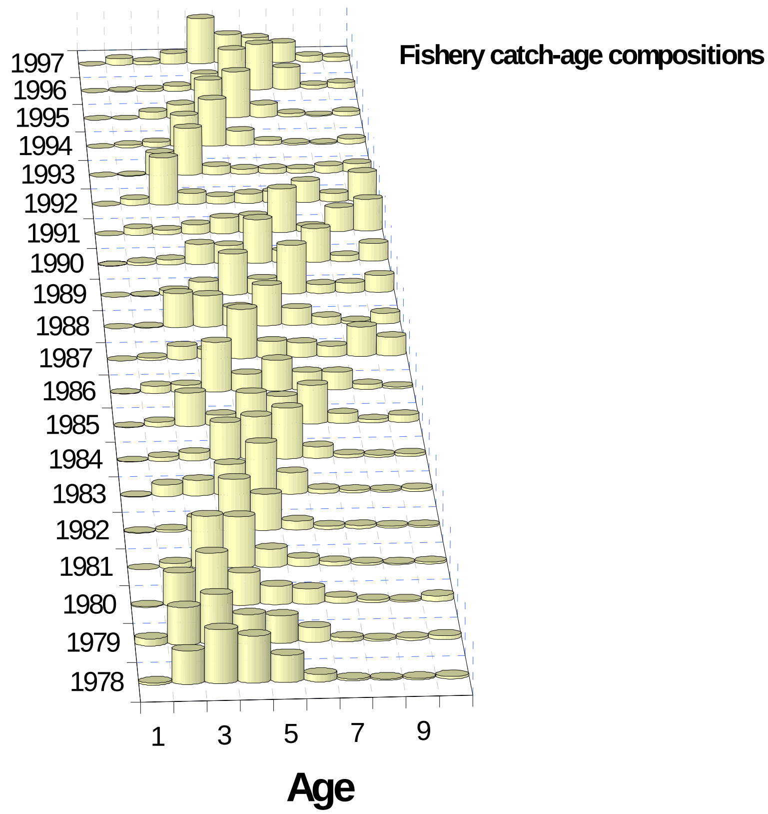


Figure 1.10. EBS walleye pollock fishery catch-at-age data (proportions).

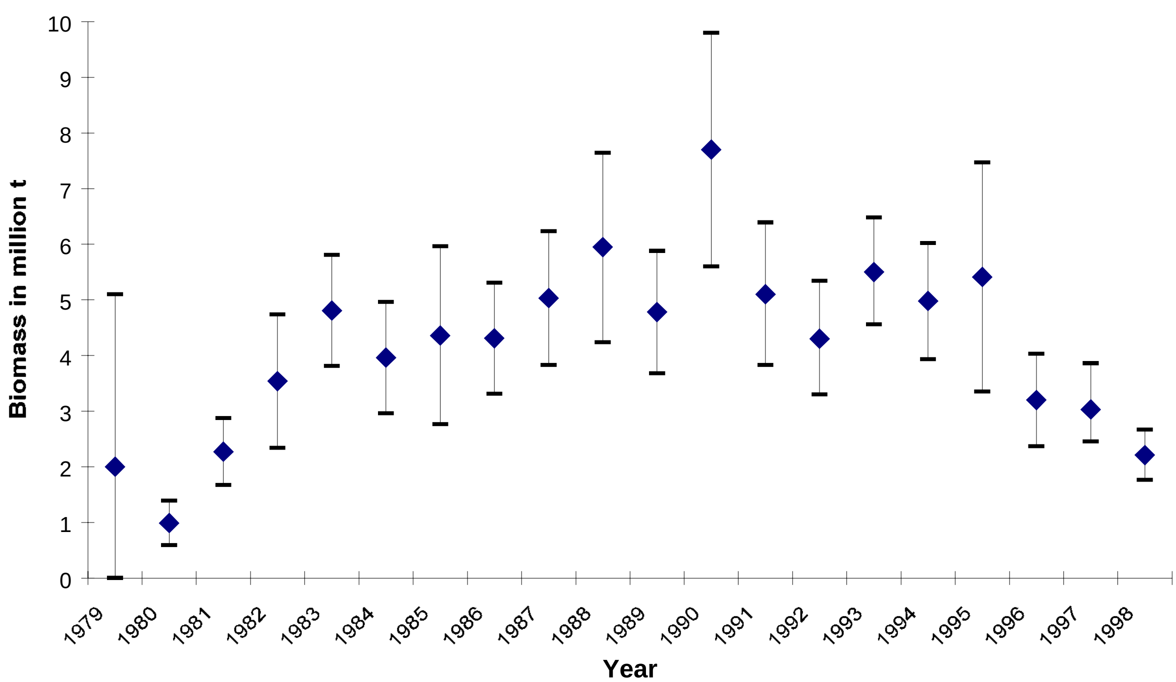


Figure 1.11. Bottom-trawl survey biomass estimates for EBS walleye pollock, 1979-1998 (note that the 1979-1981 estimates were not used in the current analyses since the survey sampling gear changed).

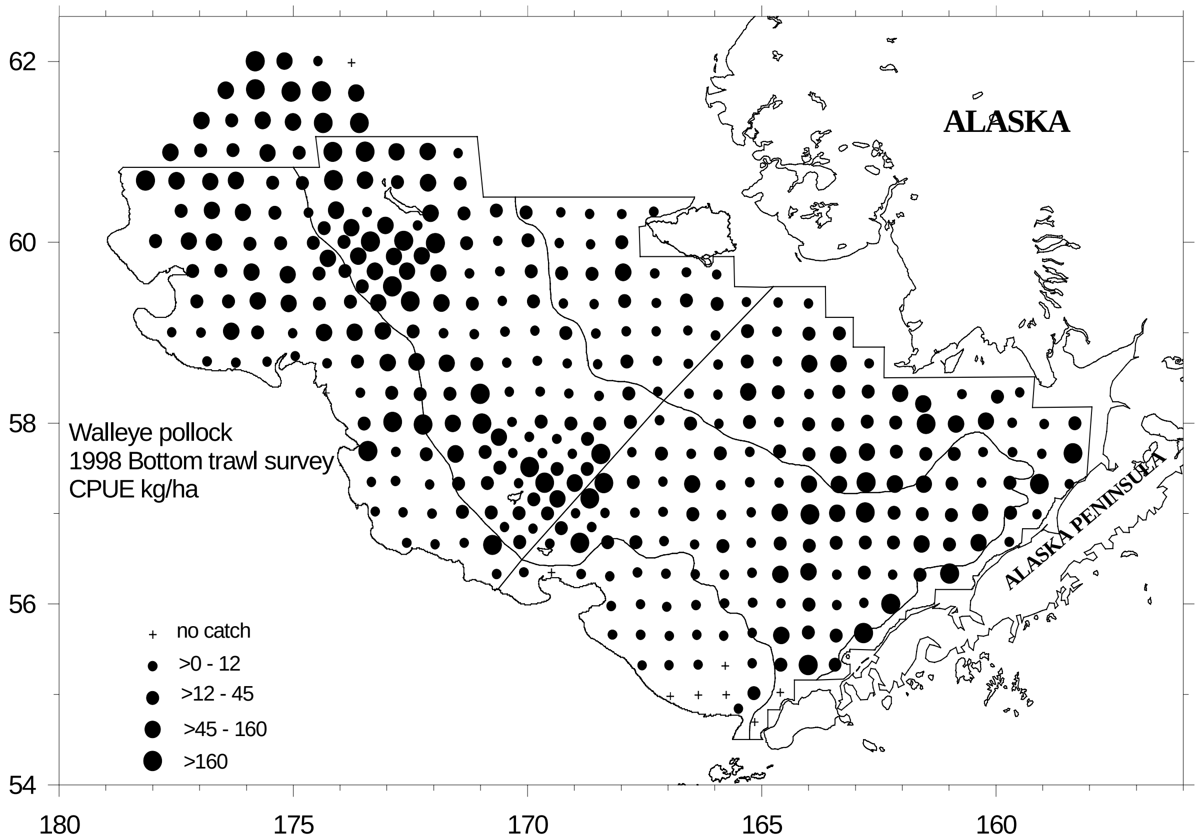


Figure 1.12. Map showing walleye pollock catch-per-unit effort observed during the 1998 NMFS EBS shelf bottom-trawl survey.

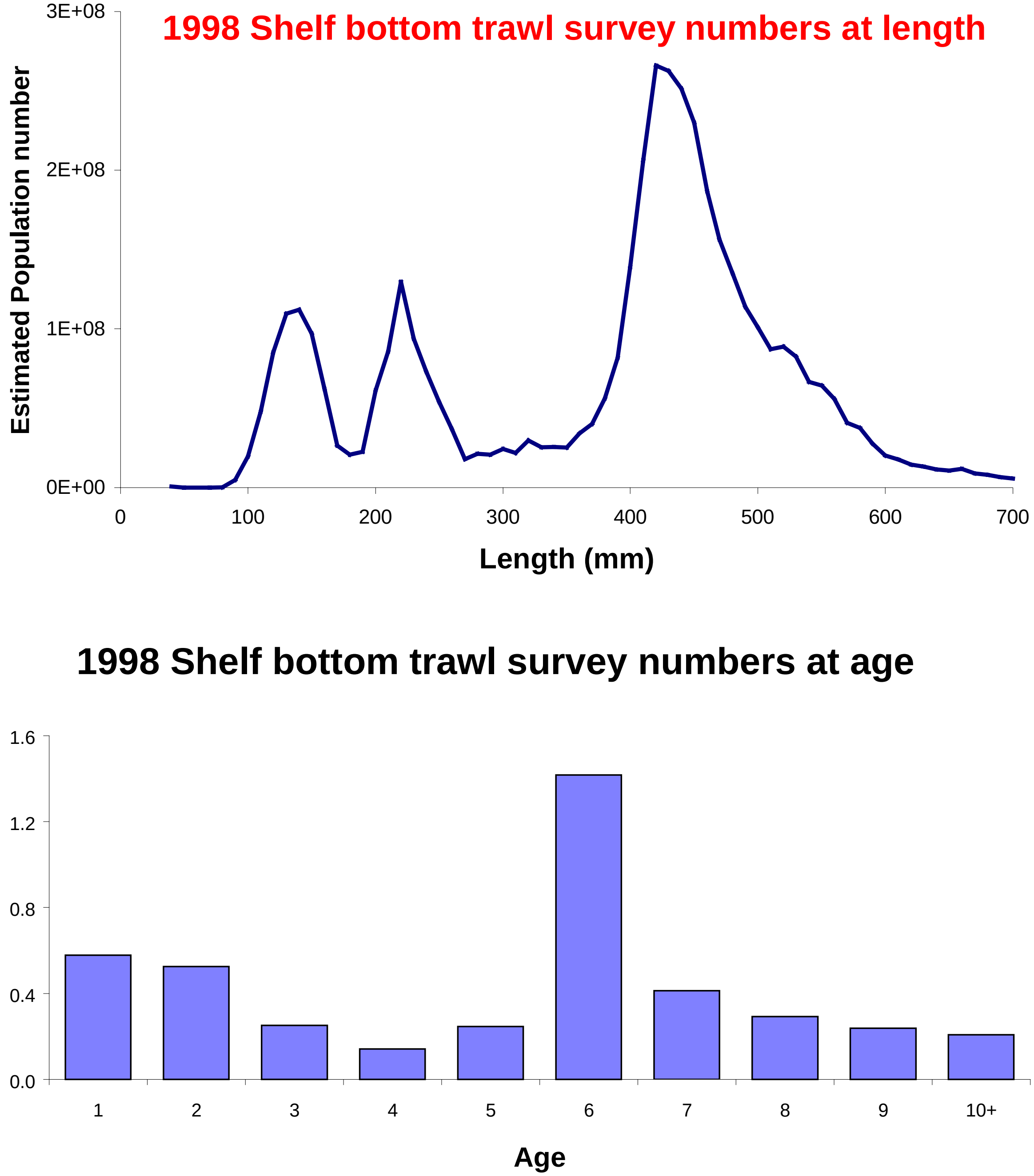


Figure 1.13. EBS pollock length (top panel) and age (bottom panel) distribution observed during the 1998 NMFS bottom-trawl survey.

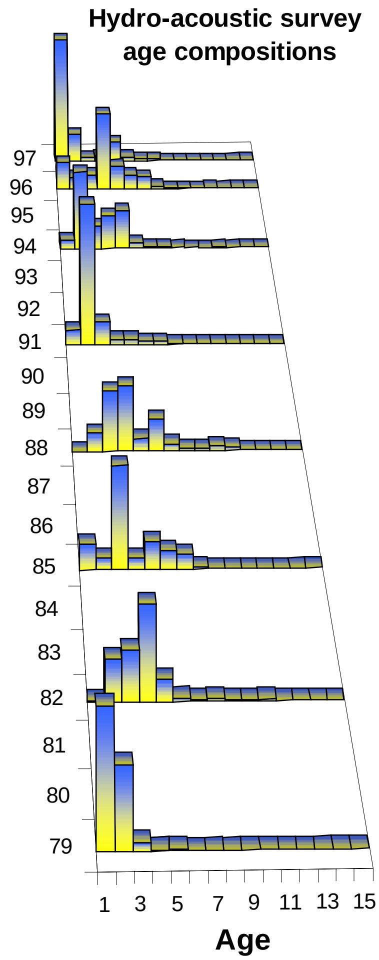


Figure 1.14. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-1997.

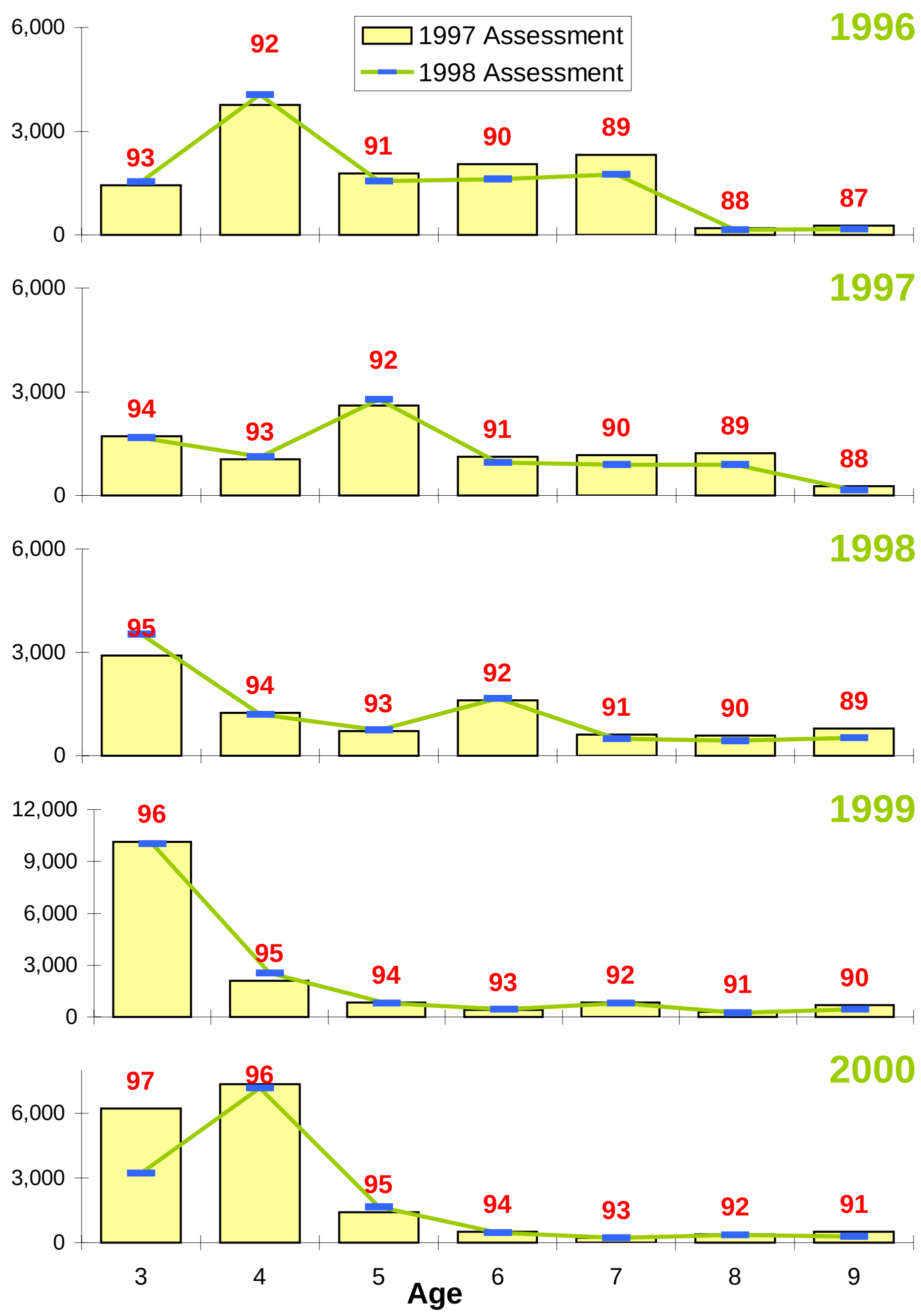


Figure 1.15. Projected EBS walleye pollock Model 1 population numbers at age compared with those presented in last year's document (Model 4 from Wespestad et al. 1997). Note that the "age 9" category represents all pollock age 9 and older.

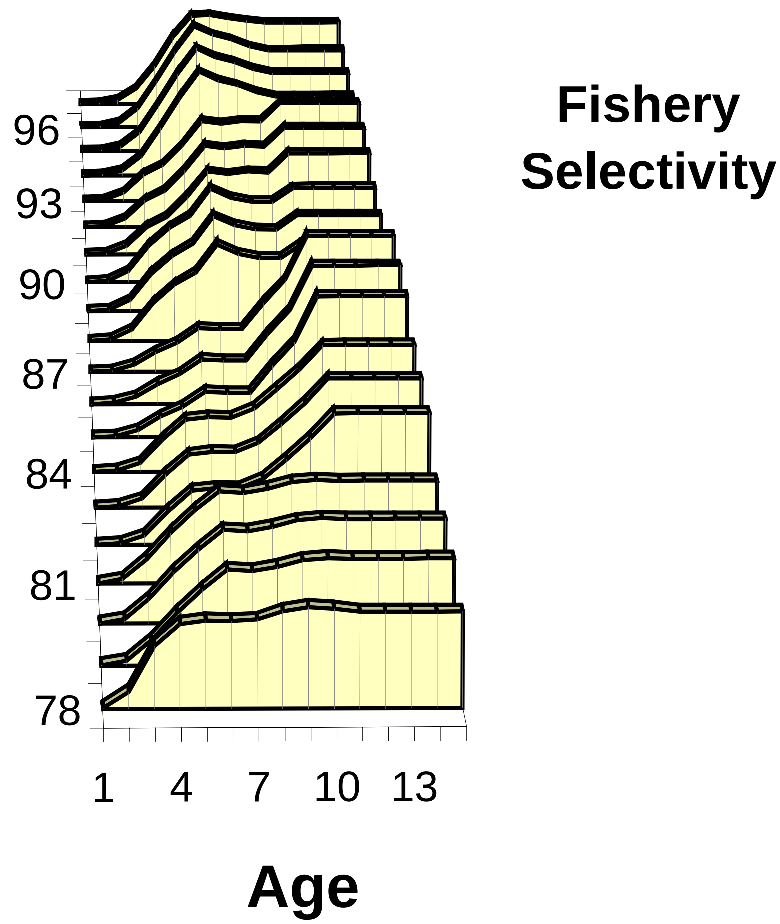


Figure 1.16. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-1998 estimated for Model 1.

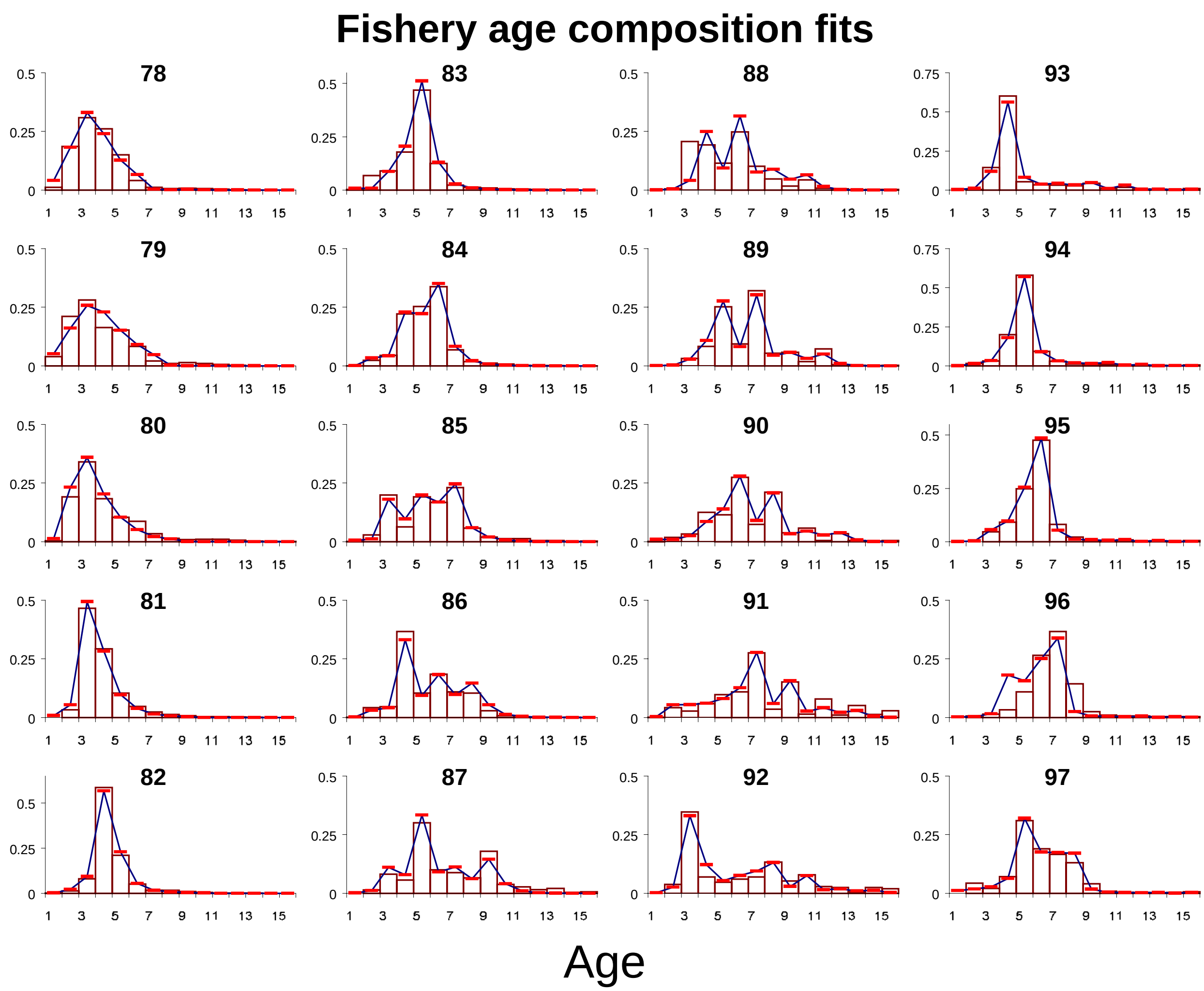


Figure 1.17. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1978-1997). Lines represent model predictions while the vertical columns represent the data.

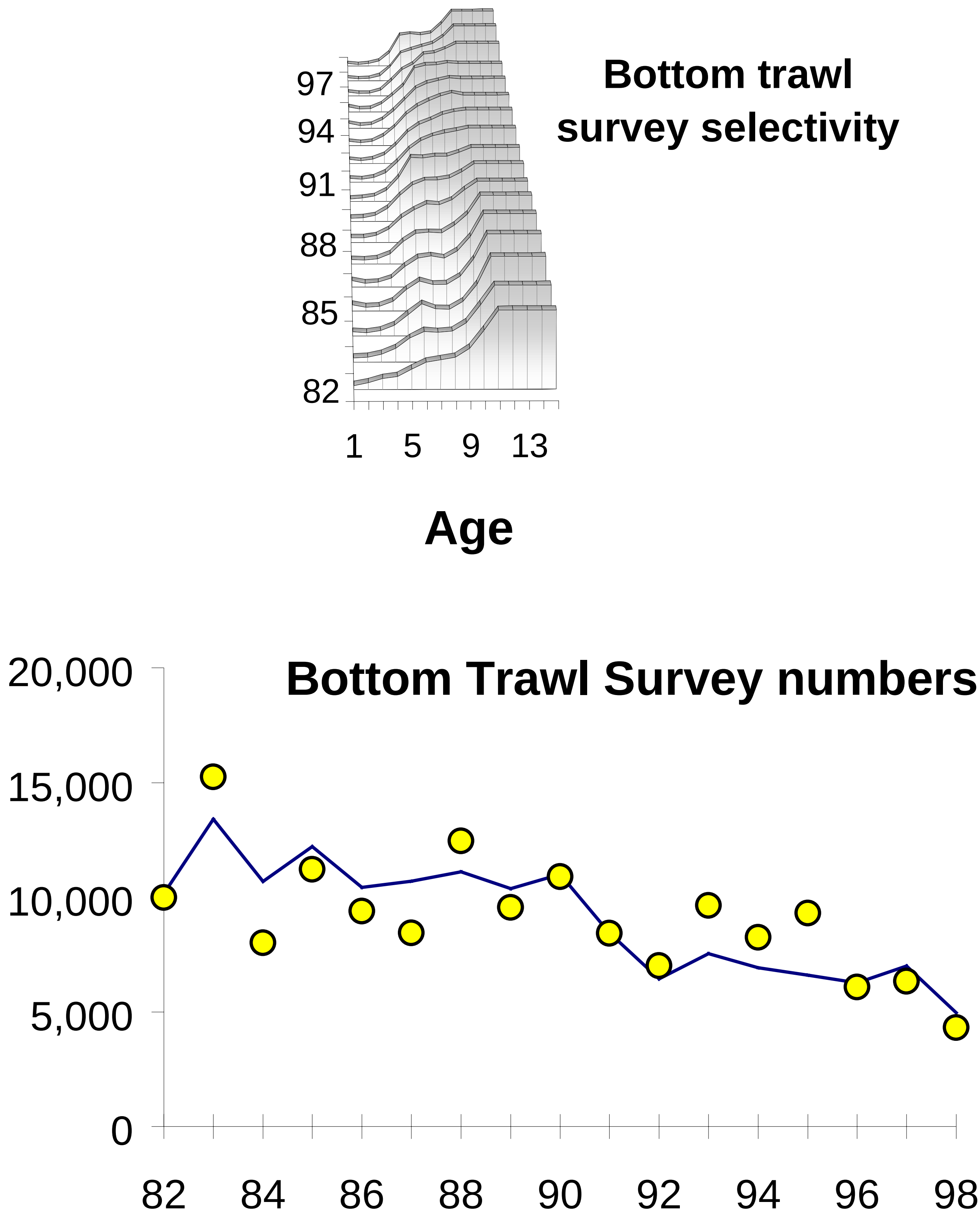


Figure 1.18. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age over time (upper panel) for EBS walleye pollock, Model 1.

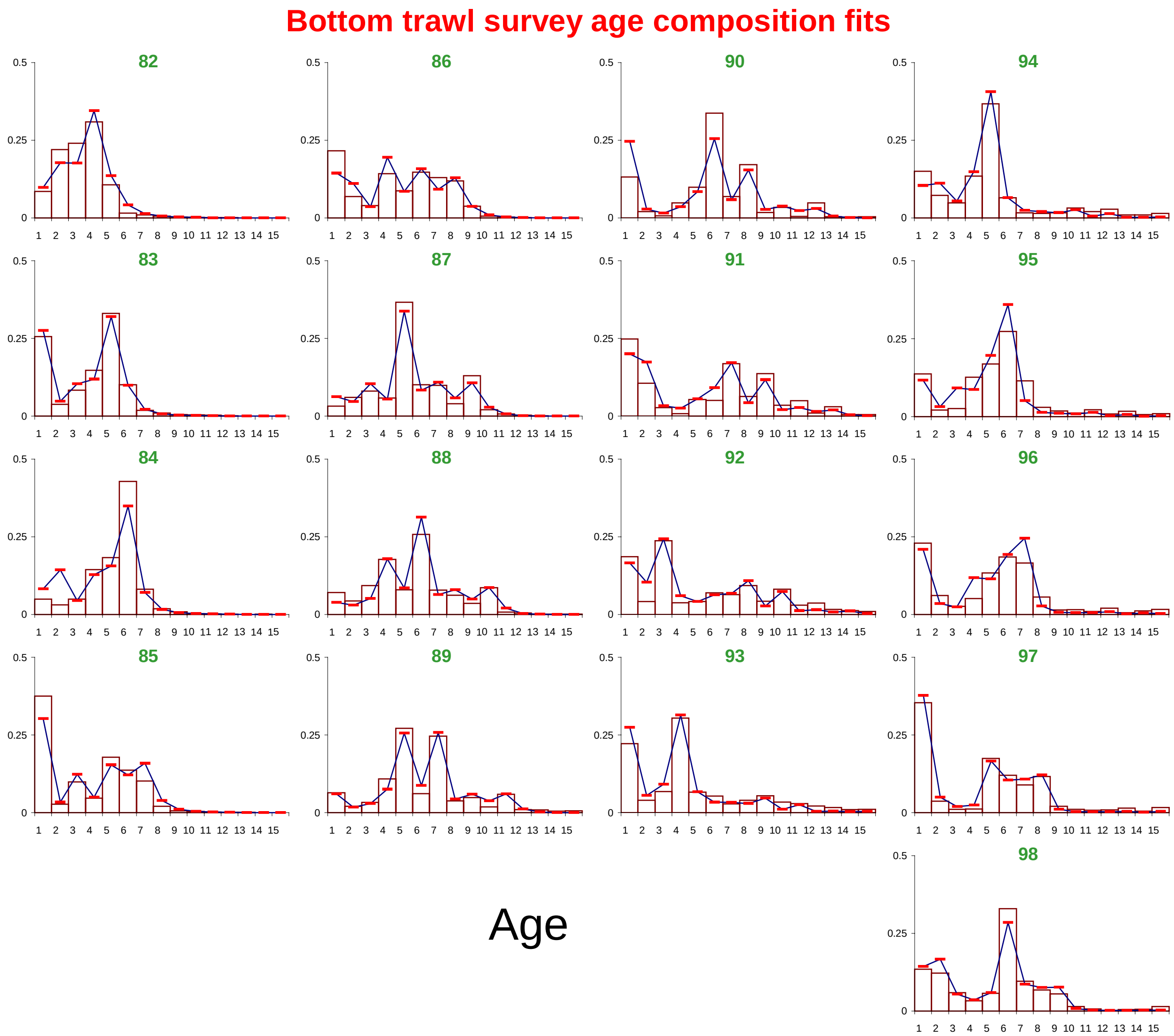
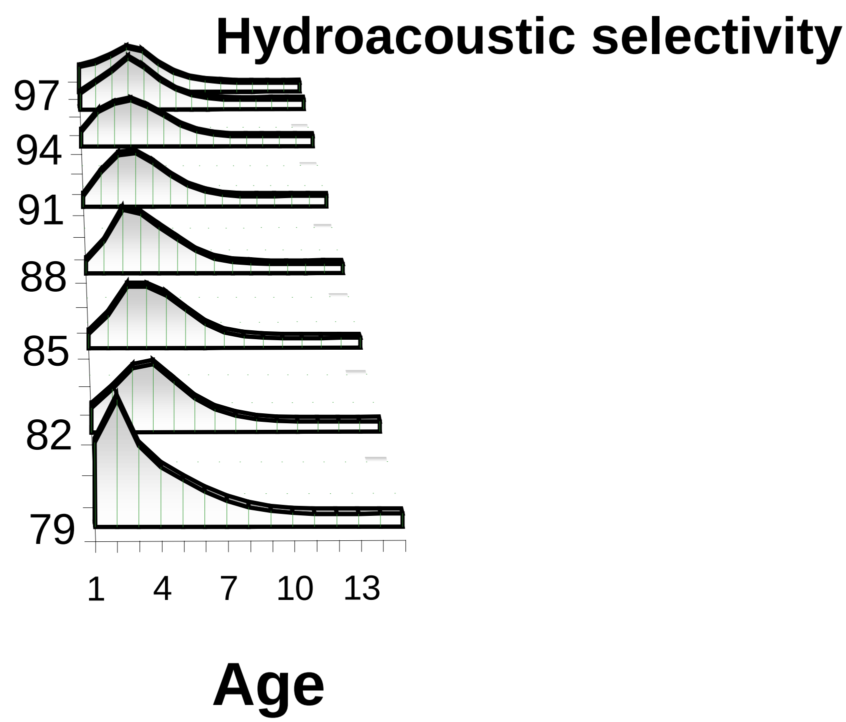


Figure 1.19. Model 1 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data.



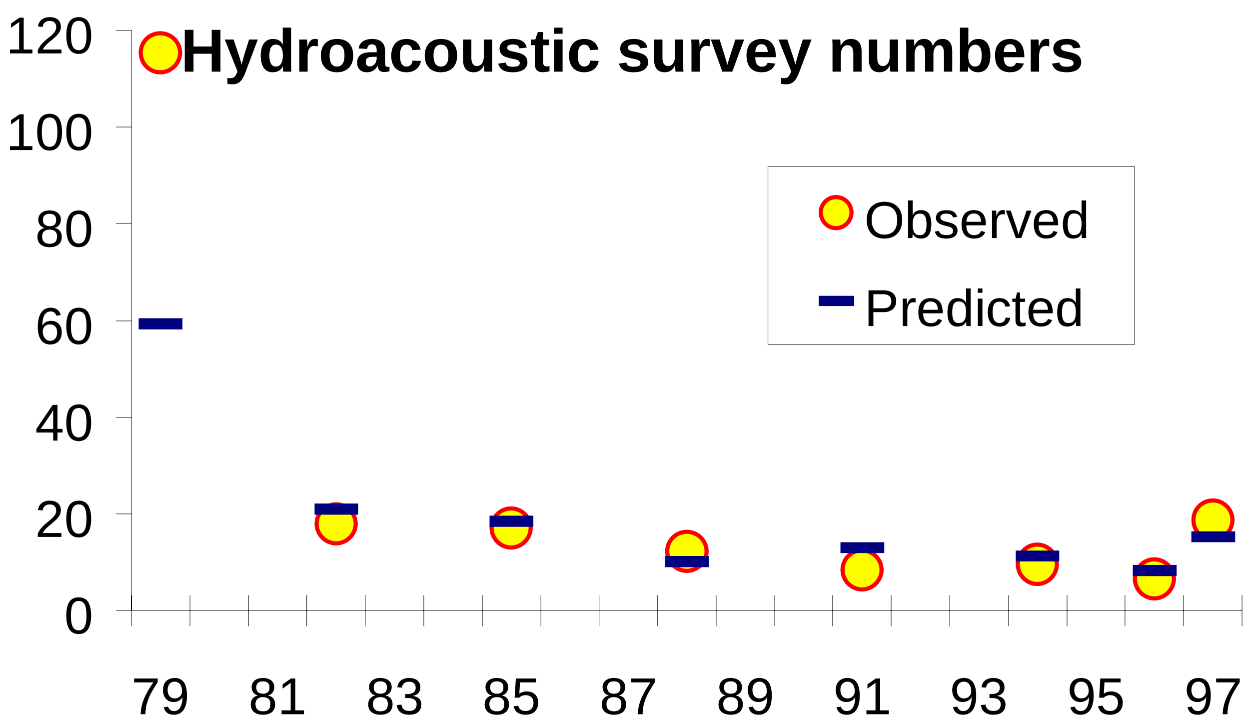


Figure 1.20. Model 1 estimates of EIT survey numbers (upper panel) and selectivity-at-age over time (lower panel) for EBS walleye pollock.

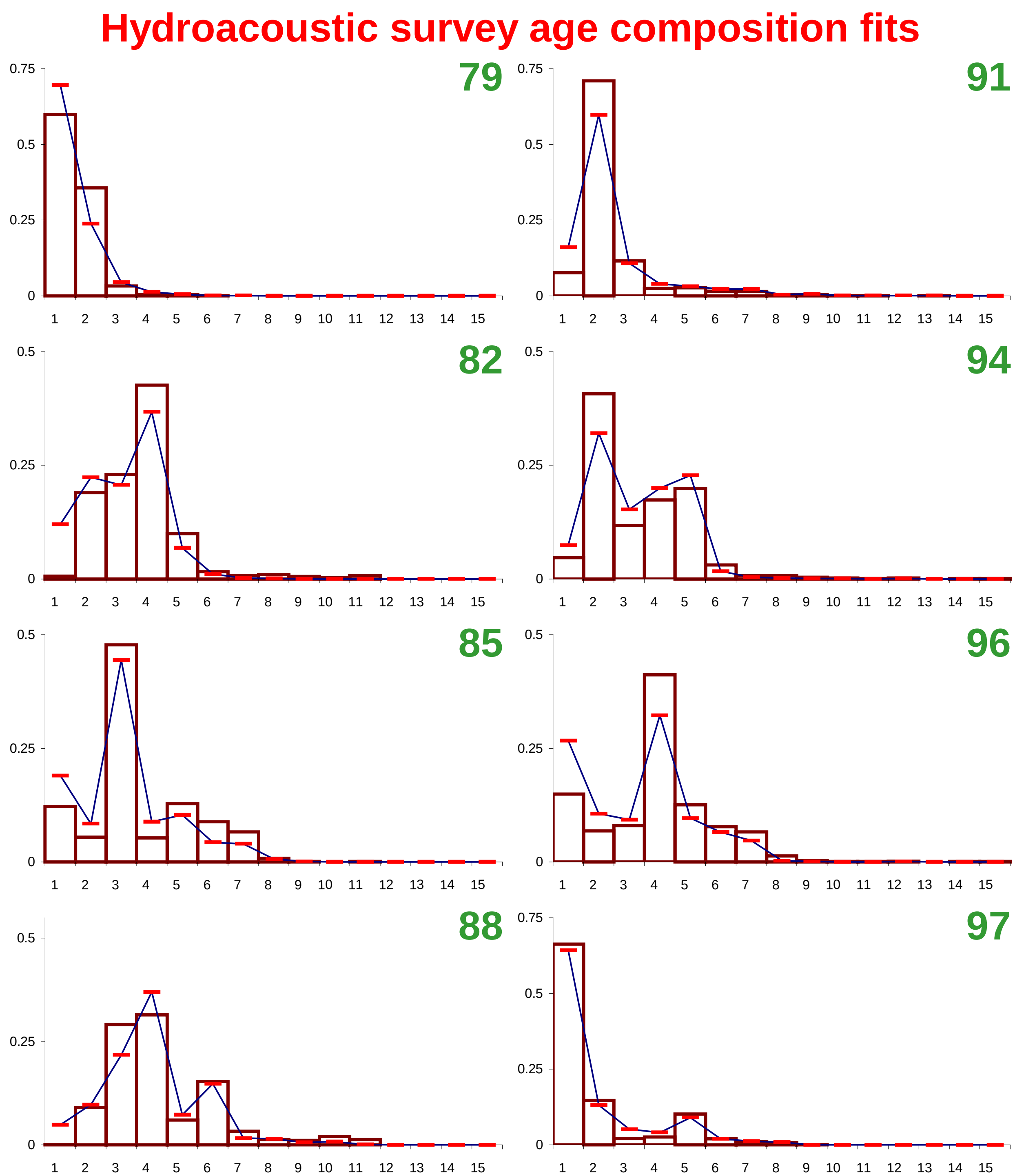


Figure 1.21. Model 1 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data.

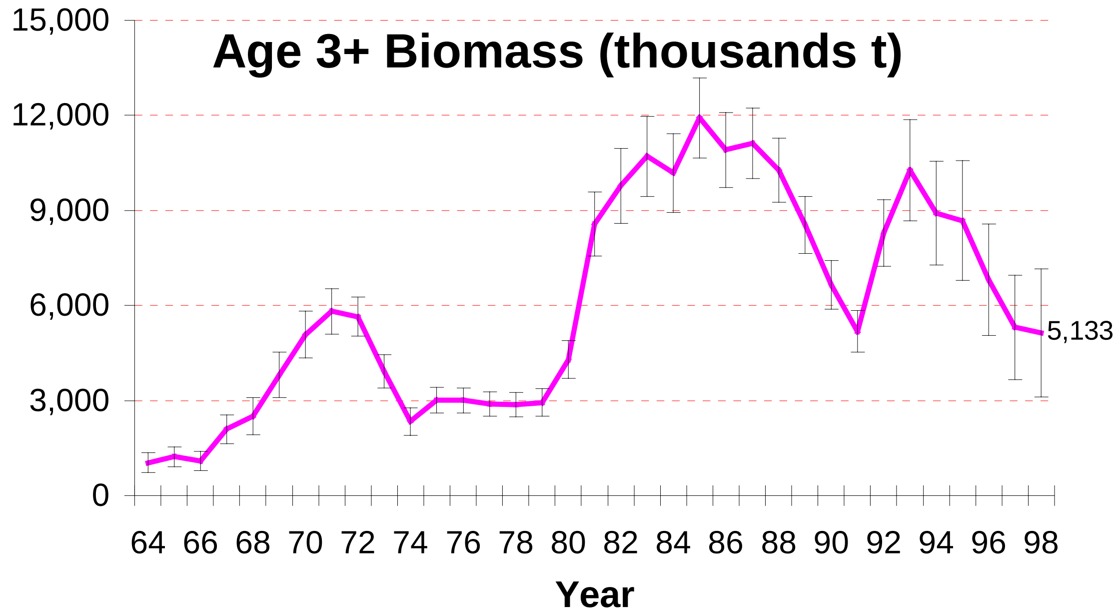


Figure 1.22. Estimated age 3+ EBS walleye pollock biomass under Model 1. Error bars represent two standard deviations of the estimate.

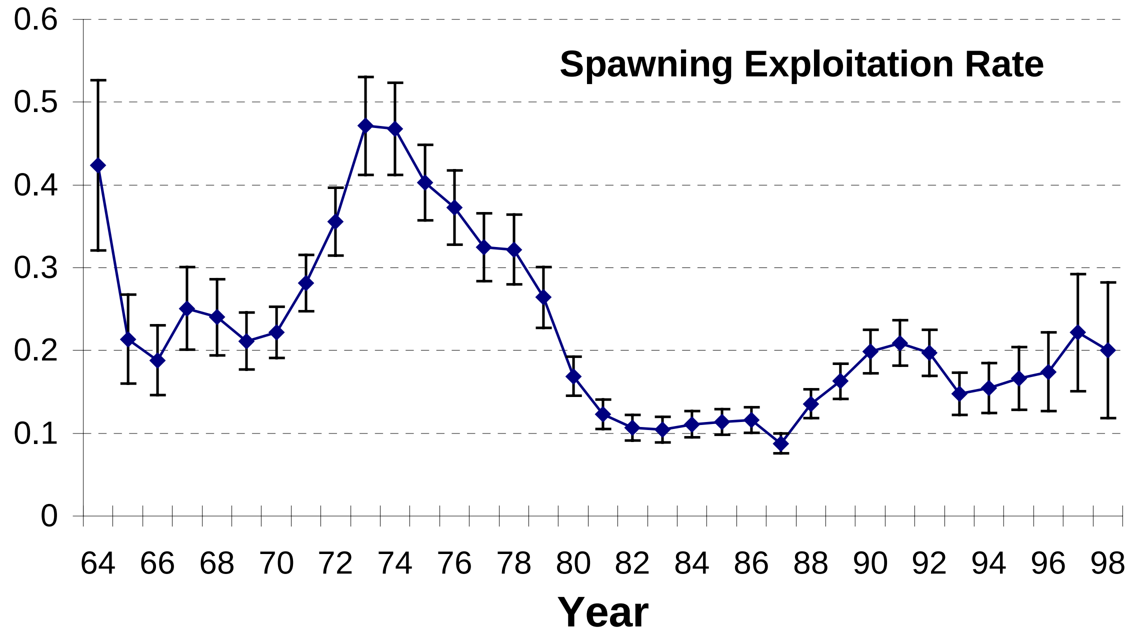


Figure 1.23. Estimated spawning exploitation rate (computed as the percent removals of spawning females each year) for EBS walleye pollock, Model 1. Error bars represent two standard deviations of the estimate.

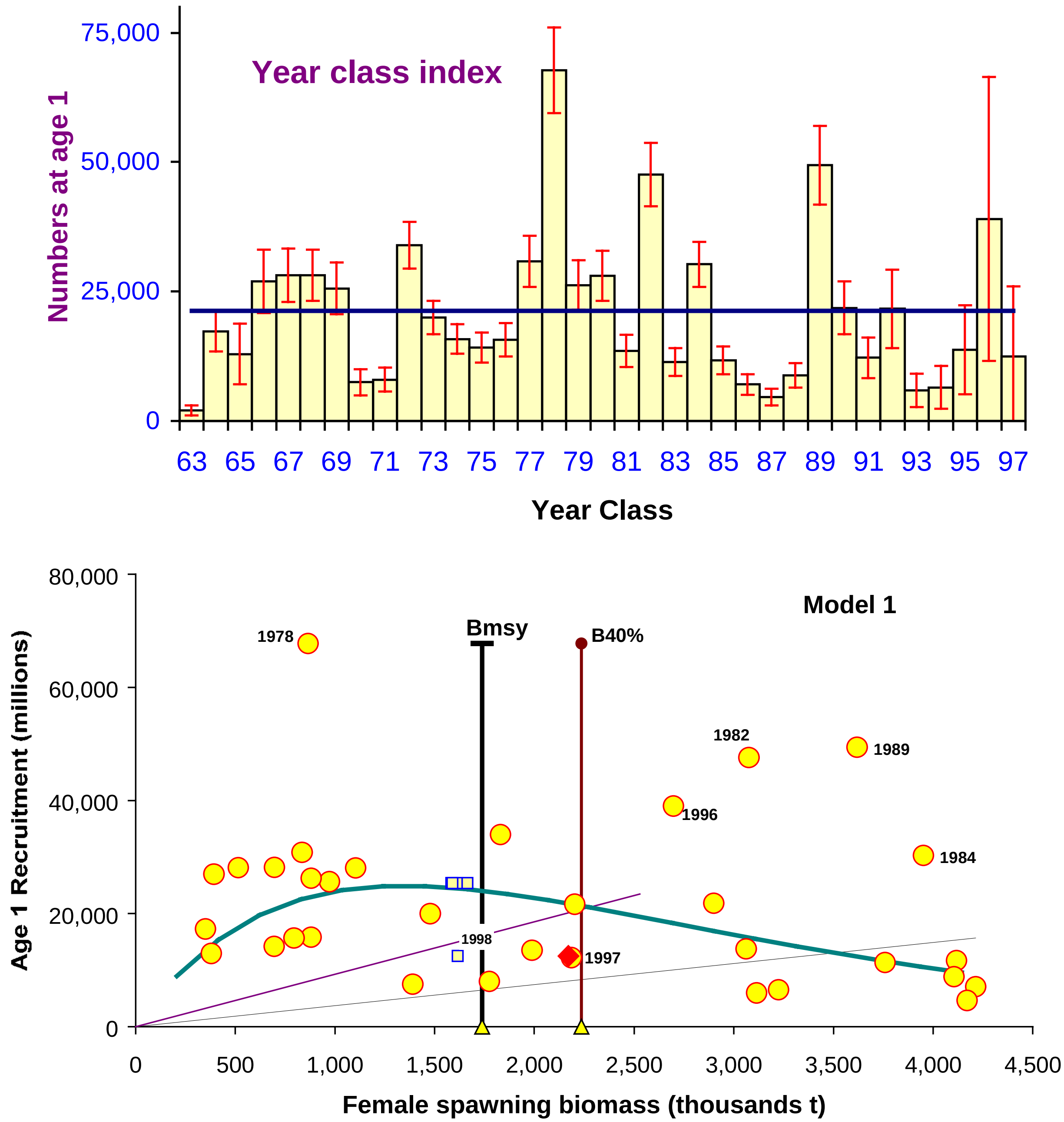


Figure 1.24. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 1. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate B_{msy} and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with diagonals representing the replacement lines with no fishing (lower line) and with fishing at the $F_{40\%}$ rate. Square symbols represent projected values with fishing at F_{msy}.

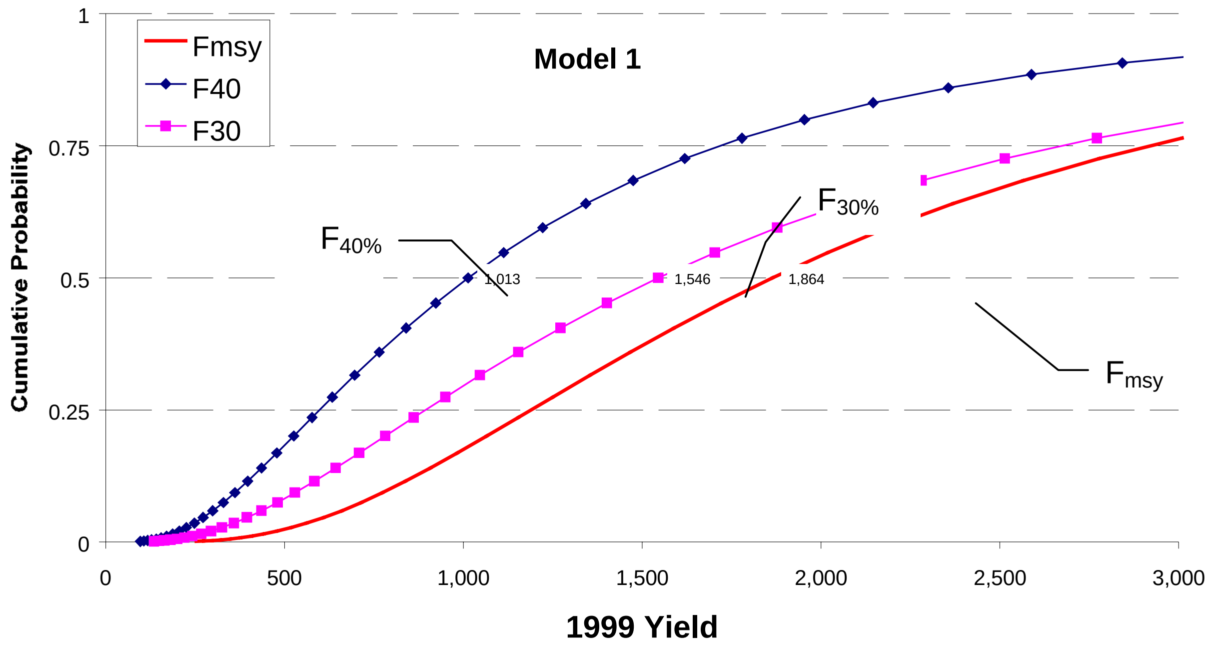


Figure 1.25. Model 1 measures of uncertainty in 1999 (unadjusted) yield for EBS walleye pollock as a cumulative distribution. Values along the curve represent the estimated probability (vertical axis) that the 1999 yield will be lower than the corresponding value on the horizontal axis.

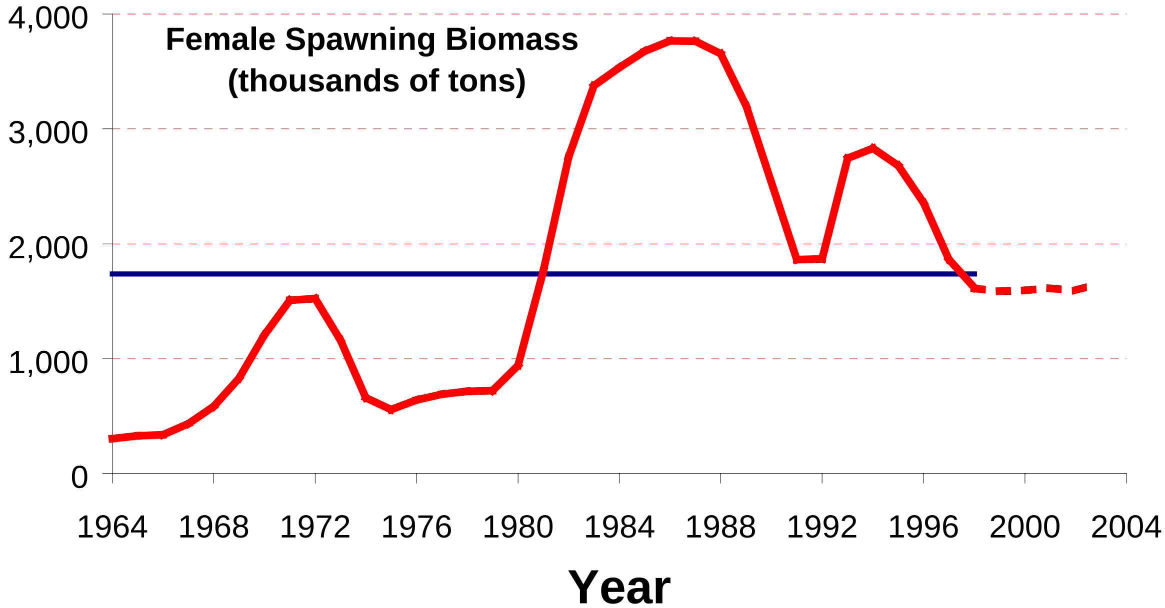


Figure 1.26. EBS walleye pollock female spawning biomass abundance trends, 1979-1998 as estimated by Model 1. Horizontal straight line represents the B_{msy} level; projections past 1998 are based on F_{msy} harvests (adjusted).

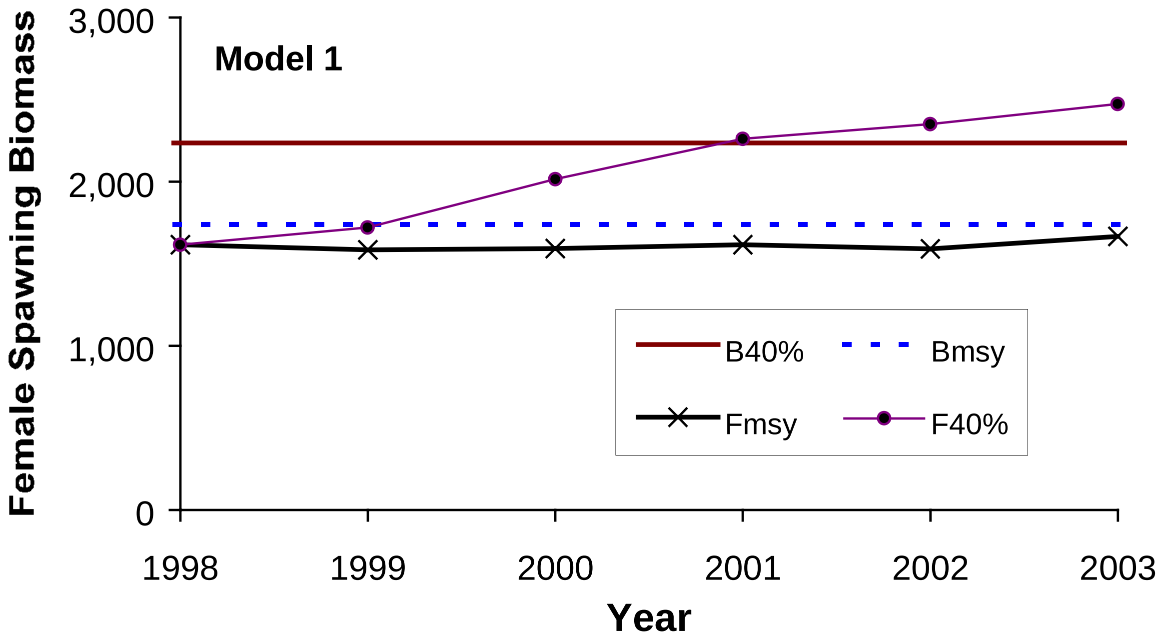


Figure 1.27. Projected **Female spawning biomass** relative to the $B_{40\%}$ and B_{msy} levels target (for EBS walleye pollock, Model 1). $B_{40\%}$ is computed from average recruitment from 1964-1998. Future harvest rates are assumed equal to the adjusted F_{msy} or $F_{40\%}$ fishing mortality rates.

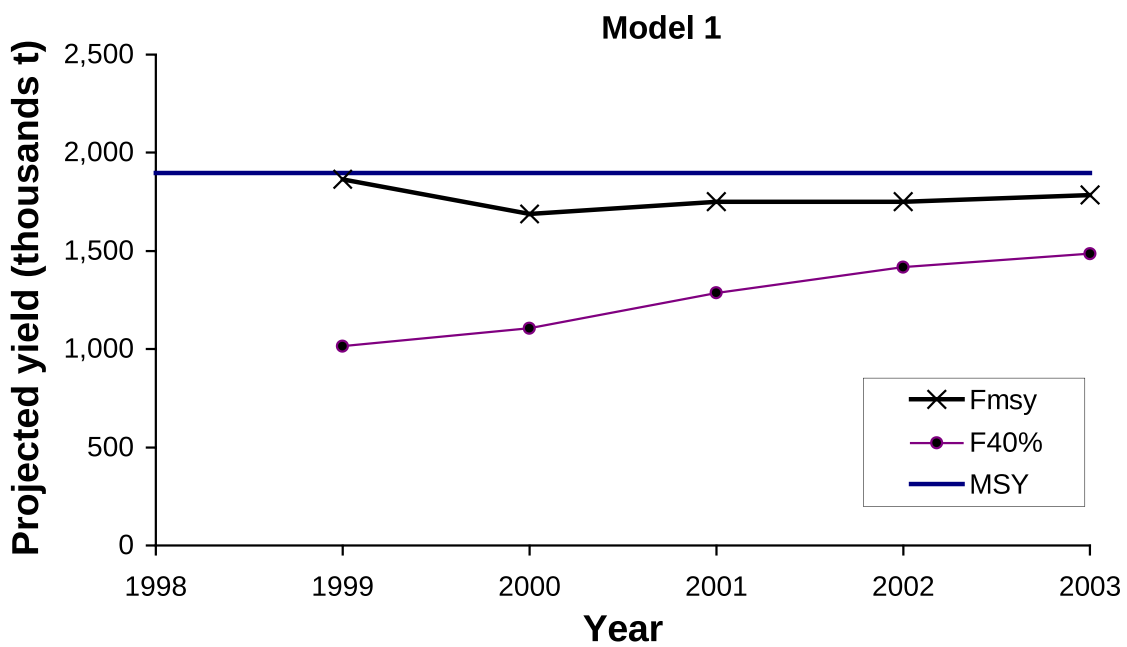


Figure 1.28. Projected EBS walleye pollock **yields** under (adjusted) F_{msy} and $F_{40\%}$ relative to the long-term expected value for MSY (horizontal line).

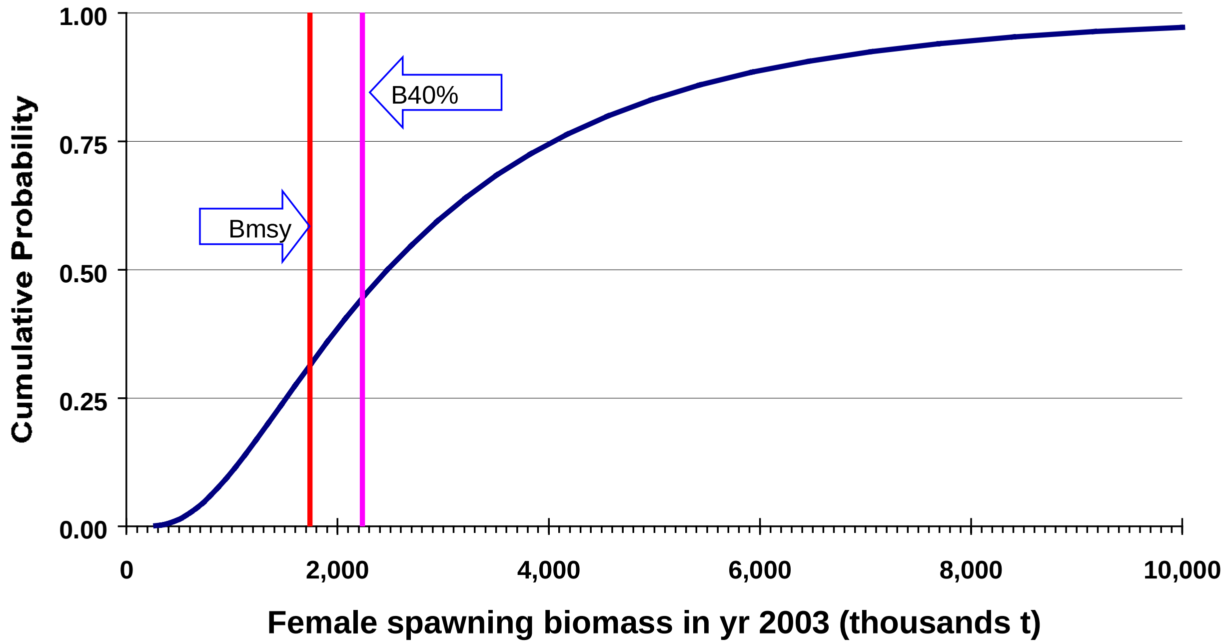


Figure 1.29. Approximate cumulative probability distribution of future female EBS pollock spawning biomass relative to B_{msy} and $B_{40\%}$. Points along the curve represent the estimated probability (vertical axis) that the female spawning biomass in 2003 will be lower than the corresponding value on the horizontal axis.

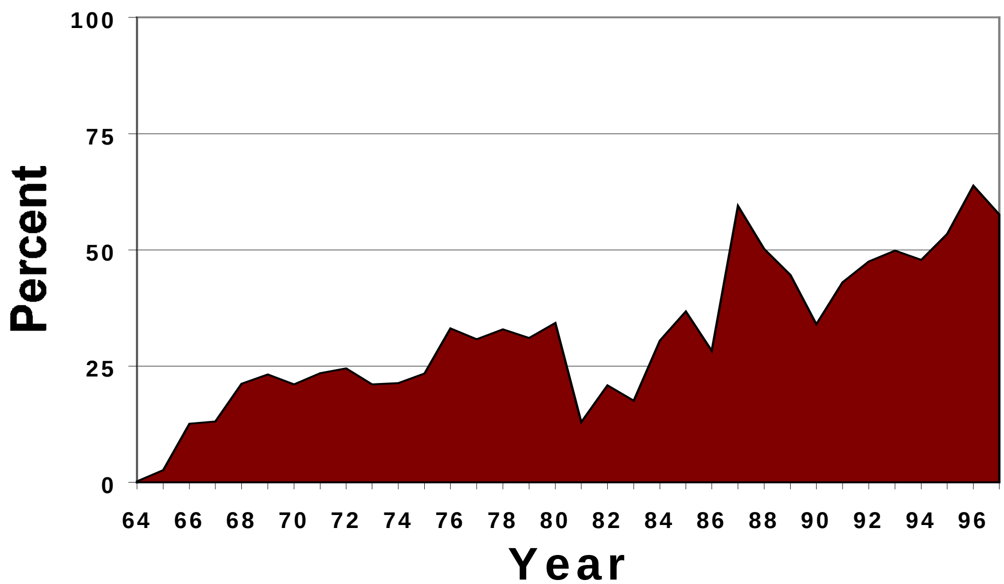


Figure 1.30. Percent of annual eastern Bering Sea and Aleutian Islands pollock caught between October and March, 1964-97.

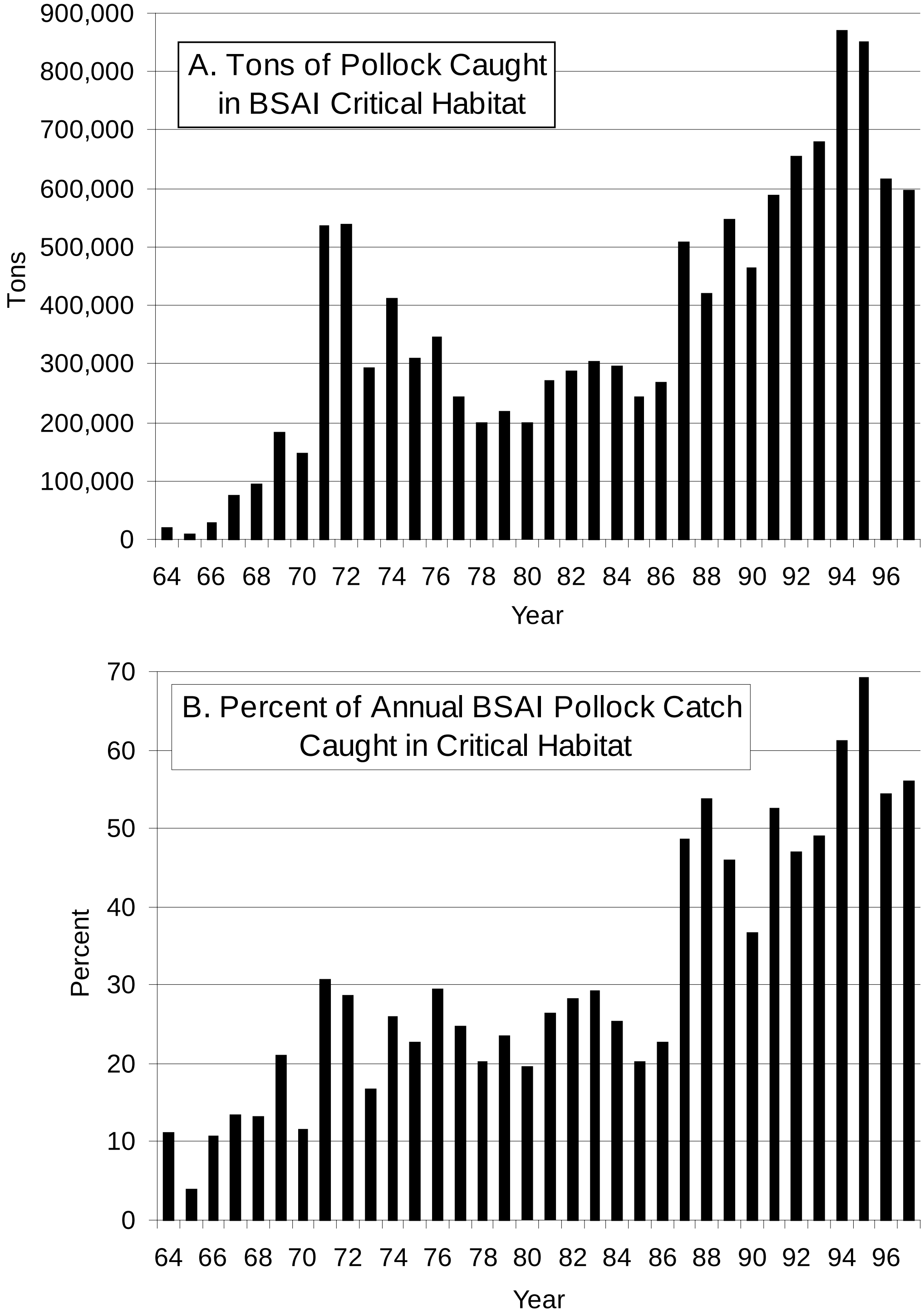


Figure 1.31. Tons of pollock (A) and percent of annual BSAI pollock catch caught in Steller sea lion critical habitat, 1964-97.

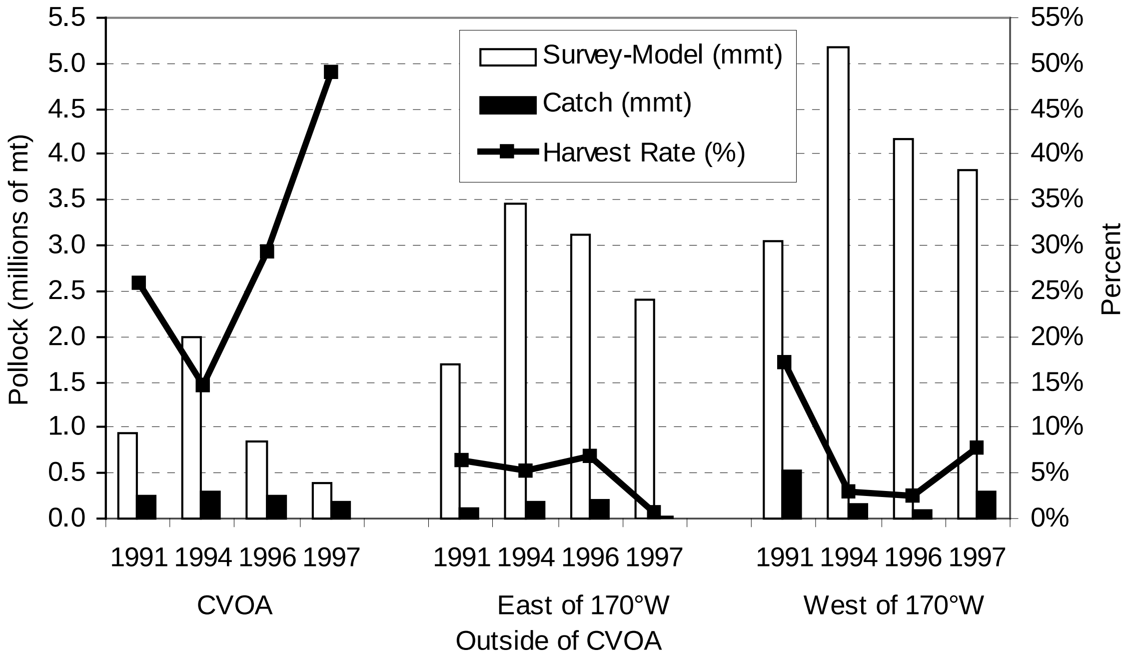


Figure 1.32. Distributions of age 3+ EBS pollock biomass (millions of mt) from the combined bottom trawl and hydroacoustic surveys and the 1997 stock assessment, commercial catches of pollock (millions of mt) from observer and blend data, and pollock harvest rates (% caught) by area in the B-seasons of 1991, 1994, 1996, and 1997.

1.14. Model details

Model structure

We used an explicit age-structured model with the standard catch equation as the operational population dynamics model (e.g., Fournier and Archibald 1982, Hilborn and Walters 1992, Schnute and Richards 1995). Catch in numbers at age in year t ($C_{a,t}$) and total catch biomass (Y_t) were

$$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-Z_{a,t}}\right)N_{t,a}, \qquad 1 \le t \le T \quad 1 \le a \le A$$

$$N_{t+1,a+1} = N_{t,a}e^{-Z_{t,a}} \qquad 1 \le t \le T \quad 1 \le a < A$$

$$N_{t+1,A} = N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}} \quad 1 \le t \le T$$

$$Z_{t,a} = F_{t,a} + M_{t,a}$$

$$C_{t\cdot} = \sum_{a=1}^{A} C_{t,a}$$

$$p_{t,a} = C_{t,a} / C_{t\cdot}$$

$$Y_t = \sum_{a=1}^{A} w_a C_{t,a} \text{ , and}$$

where

T	is the number of years,
A	is the number of age classes in the population,
$N_{t,a}$	is the number of fish age *a* in year *t*,
$C_{t,a}$	is the catch of age class *a* in year *t*,
$p_{t,a}$	is the proportion of the total catch in year *t*, that is in age class *a*,
$C_{t\cdot}$	is the total catch in year *t*,
w_a	is the mean body weight (kg) of fish in age class *a*,
$Y_{t\cdot}$	is the total yield biomass in year *t*,
$F_{t,a}$	is the instantantaneous fishing mortality for age class *a*, in year *t*,
M_{ta}	is the instantantaneous natural mortality in year *t* for age class *a*, and
Z_{ta}	is the instantantaneous total mortality for age class *a*, in year *t*.

We reduced the freedom of the parameters listed above by restricting the variation in the fishing mortality rates ($F_{t,a}$) by assuming that

$$F_{t,a} = s_{t,a}\mu^f \exp(\varepsilon_t) \qquad \varepsilon_t \sim N\left(0, \sigma_E^2\right)$$

$$s_{t+1,a} = s_{t,a} \exp(\gamma_{t,a}), \qquad \gamma_{t,a} \sim N\left(0, \sigma_s^2\right)$$

where

$s_{t,a}$ is the selectivity for age class *a* in year *t*, , and

μ^F is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. This assumption creates what is known as a separable model. If selectivity in fact changes over time, then the separable model can mask important changes in fish abundance. In our analyses, we constrain the variance term (σ_s^2) to allow selectivity to change slowly over time–thus improving our ability to estimate the $\gamma_{t,a}$. Also, to provide regularity in the age component, we placed a curvature penalty on the selectivity coefficients using the squared second-differences. We selected a simple random walk as our time-series effect on these quantities. Prior assumptions about the relative variance quantities were made. For example, we assume that the variance of transient effects (e.g., σ_E^2) is large to fit the catch biomass precisely. Perhaps the largest difference between the model presented here and those used for other groundfish stocks is in how we model "selectivity" of both the fishery and survey gear types. The approach taken here assumes that large differences between a selectivity coefficient in a given year for a given age should not vary too much from adjacent years and ages (unless the data suggest otherwise). The magnitude of these changes is determined by the prior variances as presented above. Last year we investigated the sensitivity of model results with different prior variances for comparison.

In the SAM analyses, recruitment (R_t) represents numbers of age-1 individuals. Last year our model treated recruitment simply as a stochastic process about a (geometric) mean value (R_0):

$$N_{t,1} = R_t = R_0 e^{\tau_t}, \qquad \tau_t \sim \mathrm{N}\left(0, \sigma_R^2\right) .$$

This year we added a stochastic Ricker function of spawning stock biomass:

$$R_t = B_{t-1} e^{\alpha - B_{t-1}\beta + \tau_t}, \qquad \tau_t \sim \mathrm{N}\left(0, \sigma_R^2\right) ,$$

and also a stochastic Ricker function with an environmental component (κ_t) :

$$R_t = B_{t-1} e^{\alpha - B_{t-1}\beta + \kappa_t + \tau_t}, \ \ \tau_t \sim \mathrm{N}\left(0, \sigma_R^2\right) .$$

Mature spawning biomass during year *t* was defined as:

$$B_t = \sum_{a=1}^{15} w_a \phi_a N_{at}$$

where ϕ_a, the proportion of mature females at age, was the same as that presented in Wespestad (1995).

The environmental component discussed above is derived from Wespestad et al. (1997) study on factors that appear to be critical for EBS pollock recruitment. They presented hypotheses about the relationship between surface advection during the post-spawning period and pollock survival. They found that during years when the surface currents tended north-north westward along the shelf that year class strength was improved compared to years when currents were more easterly. They used the OSCURS model to simulate drift. In a subsequent analyses (Ianelli and Fournier, In Prep.) their analysis was extended to apply within a stock assessment model context. The procedure is briefly outlined as follows:

1) run the OSCURS model for 90 days in each year starting at 165W and 55.5N storing the daily locations;

2) compute the average location of the simulated drifter over the 90 day period within each year using the GMT program (Wessel and Smith 1991) ***`fitcircle`***.

3) plot these points and create a geographic grid (**A**) centered such that it covers all mean values over all years,

4) create an indicator matrix (Ψ) dimensioned such that the rows correspond to the number of years needed for the model (here 1964 – 1997) and the columns represent either the row or column index of the geographic grid. For example, say the average location of a drifter in 1980 fell within the bounds of the geographic grid cell represented by the 2nd column and 4th row, then the indicator matrix would have 2 and 4 as entries for the row corresponding to 1980.

Submit the indicator matrix as data to be read in to the model so that the values of the geographic grid matrix can be estimated where:

$$\kappa_t = A\left(\Psi_{t,1}, \Psi_{t,2}\right), \qquad \kappa_t \sim \mathrm{N}\left(0, \sigma_\kappa^2\right) \ .$$

The idea is simply that there are "good" circulation patterns and "bad" circulation patterns within the first few months after spawning.

The computation for predicting survey proportions at age and total numbers changed from the previous analyses (e.g., Wespestad *et al.* 1996, 1997). Previously we assumed that the survey was completed at the beginning of the year (prior to the fishery). This year we adjusted survey numbers to account for removals that occurred during the first part of the year allowed the effects of total mortality so that survey abundance predicted by the model for the middle of the year instead of the beginning of the year. This is more reasonable since the surveys for the EBS have always occurred during the summer months. As in previous years, we assumed that removals by the survey were insignificant (i.e., the mortality of pollock caused by the survey was considered insignificant). Consequently, a set of analogous catchability and selectivity terms were estimated for fitting the survey observations as:

$$N_{t,a}^s = e^{-0.5Z_{t,a}} N_{t,a} q_t^s s_{t,a}^s$$

where the superscript *s* denotes quantities pertaining to the survey processes. For these preliminary analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the EIT and bottom trawl surveys).

Reparameterization of the stock-recruitment function

This year we implemented a reparameterized form for the stock-recruitment relationship as by Francis (1992). For the Beverton-Holt form we have:

$$R_i = \frac{S_{i-1} e^{\varepsilon_i}}{\alpha + \beta S_{i-1}}$$

where

R_i is recruitment at age 1 in year *i*,

S_i is the biomass of female spawners in year *i*,

ε_i is the "recruitment anomaly" for year *i*,

α, β are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (*h*). The "steepness" is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$

$$\beta = \frac{5h-1}{4hR_0}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawner biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawners (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of *h* = 0.9 implies that at 20% of the unfished spawning stock size will result in an expected value of 90% unfished recruitment level recruitment. Steepness of 0.9 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988). Here we assume the expected value of steepness is 0.9 with a 20% coefficient of variation. The prior distribution was assumed to be lognormal within the range 0.2-1.0. Clearly, alternative values could be applied, particularly in the sense of taking the experience among other fish stocks (e.g., Lierman and Hilborn (1997)). Since we include a stock-recruitment curve as an integrated part of the assessment, assumptions about prior parameter values are critical, particularly if the data are non-informative. This feature also allows for computation of F_{msy} values and related quantities such as MSY, Bmsy etc. The method we develop for this is described in Addendum 1.

For this preliminary draft, we did not investigate the environmental components as in last year's document.

Parameter estimation

The objective function was simply the product of the negative log-likelihood function and prior distributions. To fit large numbers of parameters in nonlinear models it is useful to be able to estimate certain parameters in different stages. The ability to estimate stages is also important in using robust likelihood functions since it is often undesirable to use robust objective functions when models are far from a solution. Consequently, in the early stages of estimation we use the following log-likelihood function for the survey and fishery catch at age data (in numbers):

$$f = n \cdot \sum_{a,t} p_{at} \ln(\hat{p}_{at}) \,,$$

$$p_{at} = \frac{O_{at}}{\sum_a O_{at}}, \qquad \hat{p}_{at} = \frac{\hat{C}_{at}}{\sum_a \hat{C}_{at}}$$

$$\hat{C} = C \cdot E_{ageing}$$

$$E_{ageing} = \begin{pmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & & \\ b_{3,1} & & \ddots & & \\ \vdots & & & \ddots & \\ b_{15,2} & & & & b_{15,15} \end{pmatrix},$$

where *A*, and *T*, represent the number of age classes and years, respectively, *n* is the sample size, and O_{at}, $\hat{C}_{at}$ represent the observed and predicted numbers at age in the catch. The elements $b_{i,j}$ represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For model runs presented above, we assumed that ageing error was insignificant. Sample size values were fixed at 200 for the fishery data, 100 for the bottom trawl survey, and 50 for the EIT survey. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, it is well known that the standard multinomial sampling process is not robust to violations of assumptions (Fournier et al. 1990). Consequently, as the model fit approached a solution, we invoke a robust likelihood function which fit proportions at age as:

$$\prod_{a=1}^{A}\prod_{t=1}^{T}\frac{\left(\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\,\tau^2}\right\}+0.01\right)}{\sqrt{2\pi\left(\eta_{t,a}+0.1/T\right)\tau}}$$

Taking the logarithm we obtain the log-likelihood function for the age composition data:

$$-1/2\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left(2\pi\left(\eta_{t,a}+0.1/T\right)\right)-\sum_{a=1}^{A}T\log_e(\tau)$$
$$+\sum_{a=1}^{A}\sum_{t=1}^{T}\log_e\left[\exp\left\{-\frac{\left(p_{t,a}-\hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a}+0.1/T\right)\,\tau^2}\right\}+0.01\right]$$

where $\eta_{t,a} = \hat{p}_{t,a}\left(1-\hat{p}_{t,a}\right)$

and $\tau^2 = 1/n$

gives the variance for $p_{t,a}$

$$\left(\eta_{t,a}+0.1/T\right)\,\tau^2 \,.$$

Completing the estimation in this fashion reduces the model sensitivity to data that would otherwise be considered "outliers."

The contribution to the log-likelihood function for the observed total catches is given by

$$\lambda_c \sum_t \left(\log\left(O_{t\cdot} / \hat{C}_{t\cdot} \right)^2 \right)$$

where λ_c represents prior assumptions about the accuracy of the observed catch data. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include

$\lambda_\varepsilon \sum_t \varepsilon_t^{\,2} + \lambda_\gamma \sum_{ta} \gamma_{t,a}^{\,2} + \lambda_\delta \sum_t \delta_t^{\,2}$ where the size of the λ's represent prior assumptions about the variances of these random variables. For the model presented below, over 540 parameters were estimated. Most of these parameters are associated with year-to-year and age specific deviations in selectivity coefficients. For a presentation of this type of Bayesian approach to modeling errors-in-variables, the reader is referred to Schnute (1994). To easily estimate such a large number of parameters in such a non-linear model, automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries was used. This software provided the derivative calculations needed for finding the posterior mode via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gave simple and rapid access to these routines and provided the ability estimate the variance-covariance matrix for all dependent and independent parameters of interest. For key quantities of interest, e.g., current stock size, the software also produces likelihood profiles which avoids the assumption that the likelihood shape is quadratic (implied when the inverse Hessian estimates are used).

1.14.1. Solving for F_{msy} in an integrated model context

Recruitment in year *i* is given by the Beverton-Holt model

$$R_i = \frac{S_{i-1} e^{\varepsilon_i}}{\alpha + \beta S_{i-1}} \quad ,$$

and for the Ricker model as

$$R_i = S_{i-1} e^{\alpha - \beta S_{i-1} + \varepsilon_i}$$

where

R_i	is recruitment at age 3 in year *i*,
S_i	is the biomass of females spawning in year *i*,
ε_i	is the "recruitment anomaly" for year *i*,
α, β	are stock-recruitment function parameters.

Since ϕ (see below) is the expected female spawning biomass produced by a single recruit, then at equilibrium we have for the Beverton-Holt Model:

$R_{eq} = \dfrac{R_{eq}\phi}{\alpha + \beta R_{eq}\phi}$. Solving for R_{eq} gives

$$R_{eq} = \frac{(\phi - \alpha)}{\beta\phi},$$

similarly, for the Ricker model one obtains

$$R_{eq} = \frac{\ln(\phi) + \alpha}{\beta\phi}$$

with

$$\phi = \sum_{j=1}^{15+} W_j N_j s_j f_j$$

$$N_j = 1 \qquad j = 1$$

$$N_j = N_{j-1} s_{j-1} \quad 1 < j \le 25$$

Note that the survival rate, s_j, and proportion mature females, f_j, are age specific. Equilibrium yield (Y) is computed for a given exploitation rate (F), giving $Y = F \cdot \overline{B}$ where $\overline{B}$ is the average equilibrium exploitable biomass. Solving for the MSY simply involves determining the exploitation rate where yield is maximized. Analytical methods are commonly used to find this value by taking the first derivative with respect to F, setting the result equal to zero, and solving for F. Unfortunately, such analytical methods are not readily available for common forms of stock-recruitment functions used in fisheries with non-trivial age-specific selectivities. Here we implement a numerical method which solves for MSY and can be applied to a broad family of models. The method implements the Newton-Raphson technique for finding the root of an equation (here, the first derivative of yield). The steps are outlined as:

1) pick a trial F and evaluate the equilibrium yield, $f(F)$;
2) compute the first and second derivatives of yield wrt F;
3) update original trial F from 1) by subtracting the ratio $\frac{f'(F)}{f''(F)}$
4) repeat steps 1) – 3) a fixed number of times so that the final adjustment in step 3) is very small. Note, convergence is usually implemented through the use of some sort of tolerance level. However, in our case we wish maintain differentiability, therefore we use a fixed number of iterations.

In practice, finite difference approximations for the derivatives given above appear to work satisfactorily which further improves one's ability to implement this type of algorithm. That is, let

$f'(F) = \frac{f(F+d) - f(F-d)}{2d}$ and $f''(F) = \frac{f(F+d) - 2f(F) + f(F-d)}{d^2}$ where d is some small value, say 1×10^{-7}.

1.15. Aleutian Island Region Pollock

Last year we presented an updated analysis of the age-structured information available for the Aleutian Islands Region. Geographically, there are questions as to the appropriateness of defining pollock caught in the "Aleutian Islands" region as being from a separate stock. Clearly the potential that a very large fraction of removals from this area are from the EBS stock rendered interpretation of results questionable.

The 1997 Aleutian Island bottom trawl survey estimated biomass at 105.6 thousand t, an increase over the 1994 survey estimates of 86.4 thousand t. Survey biomass in this region peaked in 1983 and declining to the 1994 level. The 1994 survey indicated a strong mode of either age 1 or 2 pollock; 1992 or 1993 year-class. These fish appeared to have entered the fishable population in 1996 and have stabilized or increased pollock biomass in the Aleutian Islands.

In the Aleutian Islands region the status and dynamics of pollock are not well understood. Catch-age data are limited, and most data are from the eastern Aleutians. Trawl survey data show that most of the biomass is located in the eastern Aleutian Islands and along the north side of Unalaska-Umnak islands in the eastern Bering Sea region. Analysis is also confounded by the question of stock definition. The available data suggest that the operational "stock" for this region is currently on the order of 100 - 200 thousand tons (for age 3) and harvests in the most recent year have been on the order of 30 thousand tons. Continued harvests at around that level represent about a 20% harvest rate. This has been shown to be an appropriate level for pollock in other areas. Since the selectivity seems to be on older individuals, this rate would also be conservative on a per-recruit basis. Recent harvest patterns by area show that many fewer fish are being removed from the eastern area compared to recent history (Fig. 1.33).

It is likely that pollock in the eastern Aleutian Islands is not a discrete stock, since pollock are continuously distributed from the eastern Bering Sea. In prior assessments it was assumed that stock dynamics in the Aleutian Islands are similar to that of eastern Bering Sea pollock and the biomass trend the same. Analyses on MSY values for Aleutian Islands pollock were not pursued given, among other things, potential problems with stock definition and paucity of data for this region.

Although limited number of age-structured model runs were done on this stock last year, the results showed a fair amount of ambiguity. Consequently, until the issues of stock definition and survey interpretation are resolved, we recommend continuing the use of the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC based on Tier 5 (1997 survey biomass $\times M \times$ 0.75) of **23,760 t** at a biomass of 105,600 t (with $M = 0.3$). The OFL based on Tier 5 (1997 survey biomass $\times M$) gives **31,680 t** at a biomass of 105,600 t.

	1997	1998	1999	F
F_{abc}	17,413 – 28,000 t	23,760 t	23,760 t	0.225 = 0.75 M
$F_{overfishing}$	24,000 – 38,000 t	31,680 t	31,680 t	0.3 = M

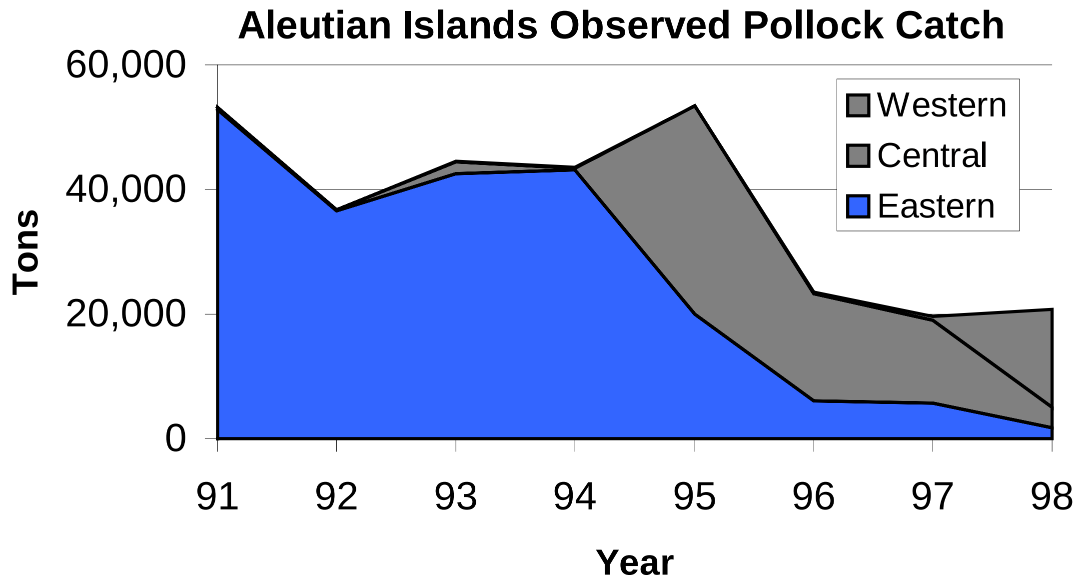


Figure 1.33. NMFS observer data estimates of pollock harvest by area within the Aleutian Islands Region. 1998 data are preliminary.

1.16. Aleutian Basin-Bogoslof Island Area

Aleutian Basin pollock spawning in the Bogoslof Island area have been surveyed annually since 1988. Pollock harvested in the Bogoslof Island fishery (Area 518) are of a noticeably different age composition than those taken on the eastern Bering Sea shelf (Wespestad and Traynor 1989). The following survey results show that population decline occurred between 1988 and 1994, and then increased in 1995. The movement of pollock from the 1989 year-class to the Bogoslof Island area was partly responsible for the 1995 increase, but the abundance of all ages increased between 1994 and 1995. The decrease between 1995 and 1996 was followed by a continued decline in 1997. This suggests that the 1995 estimate may have been over-estimated, or that conditions in that year affected the apparent abundance of pollock. The current population levels on the eastern Bering Sea shelf, and the absence of extremely large year-classes, suggests that pollock abundance will not increase significantly in the Bogoslof area in the coming years. A full report of the 1997 survey is attached (Appendix 1.A) with summary Bogoslof Island EIT survey biomass estimates, 1988-1997, as follows:

Biomass (million t)										
1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
2.4	2.1	--	1.3	0.9	0.6	0.49	1.1	0.68	0.39	0.49

The survey estimated abundance of pollock in the Bogoslof area (Area 518) increased in 1998 (Appendix 1.B). Based on the 1998 survey estimate of exploitable biomass of 0.492 million t and M = 0.2 the estimated 1998 biomass is projected to be about 0.321 million t. In 1997 the SSC determined that the estimates for $B_{40\%}$, $F_{40\%}$, and $F_{30\%}$ were reliable for this stock with values of 2,000,000 t, 0.27, and 0.37 respectively. This places Bogoslof pollock under tier 3 of Amendment 44. As in previous years, decaying the current year biomass estimate with a natural mortality rate of M = 0.2 gives a projected stock size of 403,000 t for 1999. The maximum allowable F_{abc} allowed under tier 3b is computed as:

$$F_{abc} \le F_{40\%} \times \left(\frac{B_{1999}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.27 \times \left(\frac{403{,}000}{2{,}000{,}000} - 0.05 \right) \Big/ (1 - 0.05) = 0.043$$

Using a fishing mortality rate of 0.043 translates to an exploitation rate of 0.042 which when multiplied by 403,000 t, gives a **1999 ABC of 17,000 t for the Bogoslof region.**

The OFL fishing mortality rate is computed under tier 3b as follows:

$$F_{OFL} \le F_{30\%} \times \left(\frac{B_{1999}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.37 \times \left(\frac{403{,}000}{2{,}000{,}000} - 0.05 \right) \Big/ (1 - 0.05) = 0.059$$

A fishing mortality of 0.059 translates to an exploitation rate of 0.057 which, when multiplied by a projected biomass of 403,000 t gives a **1999 OFL of 23,000 t**.

The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish belong to the same "stock", which as 4-5+ old adults, are distinct from eastern Bering Sea pollock. Data on the age structure of Bogoslof-Basin pollock show that a majority of pollock in the Basin originated from year-classes that are strong on the shelf, 1972, 1978, 1982, 1984, 1989. The mechanism causing pollock to move from the shelf to the Basin appears to be density related, with the abundance in the Basin proportional to year-class size.

Differences in spawning time and fecundity have been documented between eastern Bering Sea pollock and Aleutian Basin pollock. In addition Aleutian Basin pollock are smaller at a given age than pollock on the eastern Bering Sea shelf. Pollock in the northern shelf have a similar size at age as Aleutian Basin pollock although a very different age composition. However, Aleutian Basin pollock are likely not an independent stock. Very few pollock younger than 5 years old have ever been found in the Aleutian Basin including the Soviet portion. Recruits to the basin are coming from another area, most likely the surrounding shelves either in the US or Russian EEZ.